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THE UNIVERSITY OF ALBERTA

SELECTIVE ATTENTION AND THE JUDGMENT OF TEMPORAL ORDER

by

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DEDICATION

This work is dedicated to the wildness of the Middle Fork of the Salmon River: An inspiration to the writer who, throughout the completion of this dissertation, remembered her gentle power and kept faith in himself and in life.

ABSTRACT

The doctrine of prior entry maintains that selective attention biases the judgment of the temporal order of closely successive heteromodal stimuli. Experiments I and II were designed to replicate studies that had previously supported the doctrine. Prior entry trends, evident in both experiments, precipitated Experiment III which was designed to test the hypothesis that unequal, channel-specific processing was responsible for the perceptual phenomenon. Experiment III resulted in a massive prior entry effect which undermined the unequal processing model and led to the tentative conclusion that the prior entry phenomenon may be due to a channel-specific response bias effect.

ACKNOWLEDGMENT

Without Bob Wilberg it could never have started, much less now end. To him I owe the most because he had the courage to take a chance. He remains an on-going chapter in this writer's life.

I should also like to acknowledge Martha Ann Sheedy Frey, who despite her best efforts of persuasion, did not convince me I should have been in the mountains or at the beach or in the desert and, hence, who despite an indefatigable spirit focused on the maintenance of my mental health, did not prevent the completion of this work.

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CHAPTER I

INTRODUCTION

Components of skilled performance follow and then precede one another along an invariant temporal dimension. In perceptual-motor learning, the ability of the novice to integrate the separate components of a particular skill is the primary concern of the physical educator. In most skills, the body orientation, summation of forces, and temporal factors associated with the performance must necessarily be merged into a unitary, albeit dynamic, gestalt. At the same time, the performer's perception of the nonstatic sensory milieu must also be considered. In his discourse on the "spiral towards motor complexity," La Fave (1972) has used the term "sub-additive fusion" to describe the smoothing or automization of motor behavior in later learning. In his terminology, the learner conceptualizes task components during early phases of skill acquisition, slowly allowing nature and the "wisdom of the body" to chip off the corners of the original components to form a whole movement pattern more economical than the sum of its parts. Certainly, La Fave's description of the automation of motor sequences is in consonance with empirical evidence of motor skill acquisition. Lashley (1951) has described the capabilities of the accomplished musician who, during the performance of an arpeggio, may execute as many as sixteen successive finger strokes per second. Such high speed motor performance is learned through the additive process of component chord fusion. With practice the musician need merely to call upon the motor program for a particular

arpeggio and the effector mechanism produces the output. Such a highly skilled performance, mediated by the concatenation of distinct motor programs, is the refinement of the synthesis and eventual welding of elemental molecular components through time. Central to any discussion on skill acquisition is the notion that all perceptual-motor tasks require a time-flow progression. The ability of the skilled performer to process the fused or inter-locked components of a particular action, or scenario of actions, is constrained by the performer's ability to perceive the temporal order of event components as well as the order judgment of entire events themselves. Paramount in La Fave's (1972) model of skill development is the assumption that the operator can and does process the additive components of a skill in the correct serial order. Likewise, in the ever changing environment in which the learner or experienced performer of physical skills is often-times immersed, the valuable capacity to perceive the order of peripheral events which, depending upon their order, may necessitate the initiation of different motor commands, must also be considered a basic ability of the human operator. Indeed, the basis for success in perceptual-motor tasks relies upon the performer's ability to determine when to act and not merely what to act. In this view of the human operator, skill acquisition is based upon the fusing of discrete component movements through the dimension of time to produce a smooth, coordinated output. Fitts and Posner (1967) allude to this point when discussing the hierarchical and sequential organization of skills; and Robb (1972) discusses the temporal as well as spatial information of motor skill retention by suggesting that the encoding of temporal patterning may be more fragile than the spatial qualities of particular movements.

Generally, the temporal characteristics of even continuous and coherent motor skills (Fitts, 1964) more easily decay or are more interfered with than the component subroutines. In view of the above, the performer's ability to perceive the temporal order of high speed events, not only his own movements, but those environmental changes occurring during the performance, is a prime consideration in research dealing with skill acquisition and psychomotor learning.

How the human operator categorizes events in the continually changing flux of sensory information is the basic question in research dealing with perceptual processing (Dodwell, 1971). Actions in the perceptual-motor environment of games and sports are generally precipitated by a synthesis of information arriving via sensory channels, the central processing of such information, and the response capabilities of the respondent. The performer's actions in the acquisition and maintenance of motor skills are the concern of physical educators in general, and motor learning and human performance theorists in particular. By experimentally manipulating perceptual, cognitive, and volitional mechanisms, researchers have traditionally noted the changes in a performer's output to make inferences concerning the effect of these different performance processes. A major thesis underlying this study is the notion that, to fully understand the central organization of effected responses, human performance theorists must first address themselves to the primary problem of perception. It seems a tenable assumption that attempting to make inferences concerning central processes or effector mechanisms is a fruitless endeavor if the operator's subjective perception of experimentally generated sensory

information is not in correspondence with the objective input. If actions are initiated by the optimal processing of perceived information, then of primary interest is the nature of the perceived information and what affects its fidelity. This study is interested in what the human operator subjectively perceives and what influences this perception.

It has been suggested that the performer's ability to perceive the temporal order of closely-occurring, high-speed events is a primary consideration in motor skill acquisition. As such, research into temporal order judgment (TOJ) ability may provide insight into the potentiality and limitations of the perceptual-motor performance of both the learner and highly-skilled operator. The ability to judge the successiveness and order of closely-occurring temporal events is a highly sophisticated version of pattern recognition. As Dodwell (1971) has stated above, how the human operator categorizes events or identifies patterns is the basic question in research dealing with perceptual processing. In this regard, this study addresses itself to the nature of subjective perception by requiring a judgment of the temporal order of closely-occurring heteromodal stimulus events under different experimental treatments. Of primary interest is the effect on TOJ ability when the attentional focus of the operator is experimentally manipulated. More precisely, this study attempts to test the hypothesis that perception is biased by the attentional set of the operator. This point of view, known in experimental psychology as the doctrine of prior entry, will be more fully expanded below and in Chapter II.

Purpose

The purpose of this study is to test the prior entry hypothesis which states that the selective attention of a performer biases his perception of the objective occurrence of simultaneous or closely successive stimulus events. In its present form, the "law" of prior entry constrains all theories of high-speed pattern recognition by implying that the fidelity of objective sensory information arriving over different sensory modalities is distorted if the locus of the performer's attention is directed toward one of the modalities, to the theoretical exclusion of the other, in a closely-occurring dual stimulus ensemble. The purpose of this study is to support or refute the doctrine of prior entry with evidence accumulated in experiments designed to test its validity.

Hypothesis

The doctrine of prior entry states that if a signal is attended to, the percept of that signal will arrive in conscious awareness prior to another signal that it actually followed or with which it was in simultaneity. According to the "law" of prior entry, therefore, attention biases temporal order perception and becomes a major variable in all perceptual-motor learning and performance situations involving the temporal resolution of environmentally-generated input as well as the performer's own output, be it perceived as feedforward (efference copy) or feedback (knowledge of performance and results) information.

Viewing the human operator as an optimizing organism, it did not seem intuitively beneficial for "man" to have evolved a perceptual

mechanism that would be biased by his attentional focus. Indeed, it was questionable why such a perceptual bias would benefit an organism, which throughout its phylogenetic development and survival had to depend upon the ability to make sudden and accurate decisions based upon the actual, objective state of his environmental surround. In view of this argument, it was an underlying hypothesis that the data generated by this study would disprove or at least qualify the "law" of prior entry. In the form of a null hypothesis, it was postulated that there would be no difference in the TOJ ability of subjects when under different attentional biasing conditions.

Definitions

The following is an alphabetical listing of terms and their corresponding definitions as used in this study.

Auxiliary signal - The "complicating" signal to which no reaction is required.

Catch trial - A trial when only the auxiliary signal is presented.

Complex reaction time (CMPRT) - The amount of time from the onset of the primary signal until the subject reacts to it. A simple reaction time task complicated by an auxiliary signal.

Cue - A 500-msec stimulus, identical to the primary signal, used to remind the subject which signal is the primary stimulus.

Interstimulus interval (ISI) - The separation between the onsets of the primary and the auxiliary signals.

Point of objective simultaneity (POS) - The simultaneous onset of two signals generated by the experimenter.

Point of subjective simultaneity (PSS) - The positive or negative ISI between two signals necessary for a subject to perceive that they have synchronous onsets.

Primary signal - The signal to which a reaction is required.

Prior entry - The doctrine proposed by Titchener (1908) that hypothesizes that TOJ ability is biased by the attentional locus of the performer.

Simple reaction time (SRT) - The amount of time from the onset of a signal until the subject's first overt response to it.

Temporal order judgment (TOJ) - The reported temporal ordering of the onsets of the primary and auxiliary signals.

Temporal order judgment (auditory) (TOJAUD) - The TOJ ability of the subject when under an auditory attentional bias.

Temporal order judgment (cutaneous) (TOJCUT) - The TOJ ability of the subject when under a cutaneous attentional bias.

Temporal order judgment (no bias) (TOJNO) - The TOJ ability of the subject when not under an experimentally controlled attentional bias.

Temporal order judgment (visual) (TOJVIS) - The TOJ ability of the subject when under a visual attentional bias.

Temporal order judgment reaction time (TOJRT) - The CMPRT performance of the subject when a TOJ is also required.

Summary

Human performance theorists are concerned with the processes underlying motor behavior. The most accepted model of the human operator is to view him as an information processor. Using a left to right input/output model, researchers have manipulated the input, measured the output, and subsequently made inferences about central processes. The assumption in such research is that the experimentally generated information to be processed is subjectively perceived in perfect correspondence with the objective input before any subsequent processing occurs. This assumption, as far as temporal order resolution is concerned, may be questionable in view of the fact that a "law" of experimental psychology, the doctrine of prior entry, postulates that the perception of the temporal order of successive events is biased by the attentional focus of the performer. As such, because it is assumed that all processes underlying behavior are subsequent to perception, it is crucial to determine what exactly the human operator perceives. In particular, the primary question is whether or not attent-on affects the operator's perception of sensory information.

This study is concerned with a comparison of the temporal order judgment ability of subjects under different attentional biases. The doctrine of prior entry postulates that perception is not orthogonal to

the operator's selective attention. Contrarily, it is the initial hypothesis of this study that the "law" of prior entry may be a questionable doctrine; that the human operator has a more robust perceptual mechanism, which is not temporally influenced by the process of selective attention. The underlying thesis of this study is that temporal order perception will not be affected by the locus of attention.

CHAPTER II

REVIEW OF LITERATURE

JUDGMENT OF TEMPORAL ORDER

Complication Clock Experimentation

The order perception of simultaneous and closely successive stimuli in different sense modalities has been of experimental interest since the role of attention was first explored in such tasks at Wundt's Leipzig laboratory in the last half of the 19th century. The usual methodology of these experiments required the subject to view a clockface with a continuously rotating pointer and to indicate the corresponding clockface position of the pointer when a discrete heteromodal stimulus occurred. Such tasks were called complication experiments and were an extension of investigations into the problem of the "personal equation" in astronomical calculations (Boring, 1950; Fitts & Posner, 1967).

While different modifications of this basic paradigm were employed, (ie. von Tchisch (1885) used as many as five simultaneously presented stimuli, and Angell & Pierce (1891) shortened the arc of the clockface to the lower one-sixth of the circle), one basic finding was that on a large proportion of the trials, subjects indicated that the pointer was in simultaneity with a position on the clockface _before_ the actual locus of objective simultaneity (ie. the pointer coincided with position 8 on the dial when an auditory click was presented, yet

the subject reported position 7 as the point of subjective simultaneity). Such reports became known as negative errors and explanations for their existence occupied much scientific dialogue among early experimental psychologists.

Geiger (1902) suggested that subjective preference to mode of observations, speed of pointer sweep, practice effects, and the localization effects of a circular apparatus due to gravity working with and then against the oculo-motor muscles, were mainly responsible for subjects' performance. Negative errors were explained by von Tchisch (1885) as a "ripening of apperception," an early explanation from the Wundt laboratory. In effect, von Tchisch had suggested that subjects perceived the complicating stimulus before it actually occurred. James (1890) disagreed with this point of view, arguing that it was quite improbable that a subject would perceive a non-occurring stimulus and then not perceive it shortly thereafter when it did in fact occur. Other hypotheses for negative errors were explained in terms of a faster auditory and slower visual reaction time (Angell & Pierce, 1891); the psychological problem of interrupting the visual percept of movement (the pointer) and substituting therefor a percept of position (James (1890); and even due to the subject's desire to do as well in observations as his fellows (Geiger, 1902). Titchener (1908) felt that assigning physiological or psychological factors to explain the occurrence of negative errors in complication experiments, was an unnecessary labor. To Titchener, the problem was one of attention: the subject was predisposed to process the non-visual stimulus (ie. bell, tactual impression, etc.); therefore, at the moment that the stimulus occurred, attention was shifted to the last visual input that

had been processed, that information becoming the subject's report. Thus, if the bell objectively occurred with the pointer at 5, the last visual information processed would have been 4, and since the arrival of the auditory signal delayed the processing of any new visual information, a negative error would be the result. Titchener concluded his discussion of the problem by stating that "the stimulus, for which we are predisposed, requires less time than a like stimulus, for which we are unprepared, to produce its full conscious effect (p. 251)." This "law" of attention became known as the doctrine of prior entry.

The Prior Entry Hypothesis

Dunlap (1920) described a number of observational techniques used by subjects in the complication experiment which he felt were the causes of the characteristic results that had been generated. Because these methods were considered a product of the experimental technique employed, he inferred that the prior entry effect was an artificial byproduct of the complication clock apparatus. This evidence, when augmented by Geiger's (1902) finding that a gravitational interaction with the oculo-motor musculature produced characteristic "locational" errors in complication clock tasks, somewhat discredited Titchener's "law" of attention, relegating negative errors, the mediators of a prior entry hypothesis, to a confounding phenomenon of the experimental apparatus.

To test the law of prior entry, and forego the problems which Dunlap had associated with the previously used apparatus, Stone (1926) employed a different experimental paradigm. Her task required subjects to perceive an auditory-tactual complication at different interstimulus

intervals, with each pair of signals discretely presented after a warning signal. Subjects were given varying instructions of attentional set and were required to report which stimulus occurred first. Stone concluded that the latent time for a sensation which the observer was attending to appeared to be less than the latent time of the sensation not being attended. These results gave credibility to Titchener's "law" in that the prior entry effect, which Stone estimated at approximately 50 msec, appeared to exist for discrete complicating stimulus ensembles as well as for the continuous stimulus displays of the earlier researchers.

Forty-five years after Stone's work, Sternberg, Knoll, & Gates (1971) repeated her experiment, only unlike Stone or any of the previous workers in this area, these authors attempted to control the attentional bias by something other than instructions, and measured their success by something other than the prior entry effect itself. To do this they combined judgments of temporal order with a reaction time task in which subjects reacted to one of the two stimuli (the primary signal), while withholding a reaction to the other (the auxiliary signal). A random half of the trials were reaction trials requiring both a reaction to the primary signal and an order judgment, and the other half were catch trials, requiring no response. Both kinds of trials began with a warning signal. There followed a cue, that was similar to the primary stimulus (to remind the subject that he was reacting to one of the two stimuli during that session), and then another warning signal. On a catch trial these preliminary signals were followed only by the auxiliary signal. Any reactions to these trials were penalized, although the experimenters

did not describe the nature of the penalty. On a reaction trial, both signals occurred, with a positive or negative interval between them (ie. interstimulus interval -90 (ISI_{-90}) indicated that a cutaneous signal preceded onset of an auditory signal by 90 msec; ISI_{30} indicated an auditory lead of 30 msec over cutaneous). The subject pulled a lever as quickly as he could after the primary signal occurred, and then indicated which of the two signals seemed to occur first. Control procedures were employed to test if the concurrent temporal order judgment (TOJ) task would bias the reaction times as well as to determine the effect of the reaction time task on TOJ precision. The authors indicated that subjects were able to maintain reaction time performance almost perfectly when order judgments were added and that subjects did not reduce the precision (slope) of their order judgments despite the concurrent reaction time task. The results of the Sternberg, et al. study are idealized in Figure 1. The ordinate is the probability of the subject reporting that the auditory stimulus occurred first. Across the abscissa, from left to right, are the ISIs employed, with the cutaneous signal becoming more delayed relative to the auditory stimulus. The curve to the left shows the psychometric function when subjects were under an auditory attention bias (ie. trials when subjects were reacting to the auditory signal); the right hand curve is the same function for a cutaneous bias. Sternberg, et al. assigned the 50%-point of the psychometric function as the point of subjective simultaneity in that condition and the difference between the two 50%-points (ie. the distance between the curves), was considered the measure of the prior entry effect. For the subjects in their study, the mean prior entry

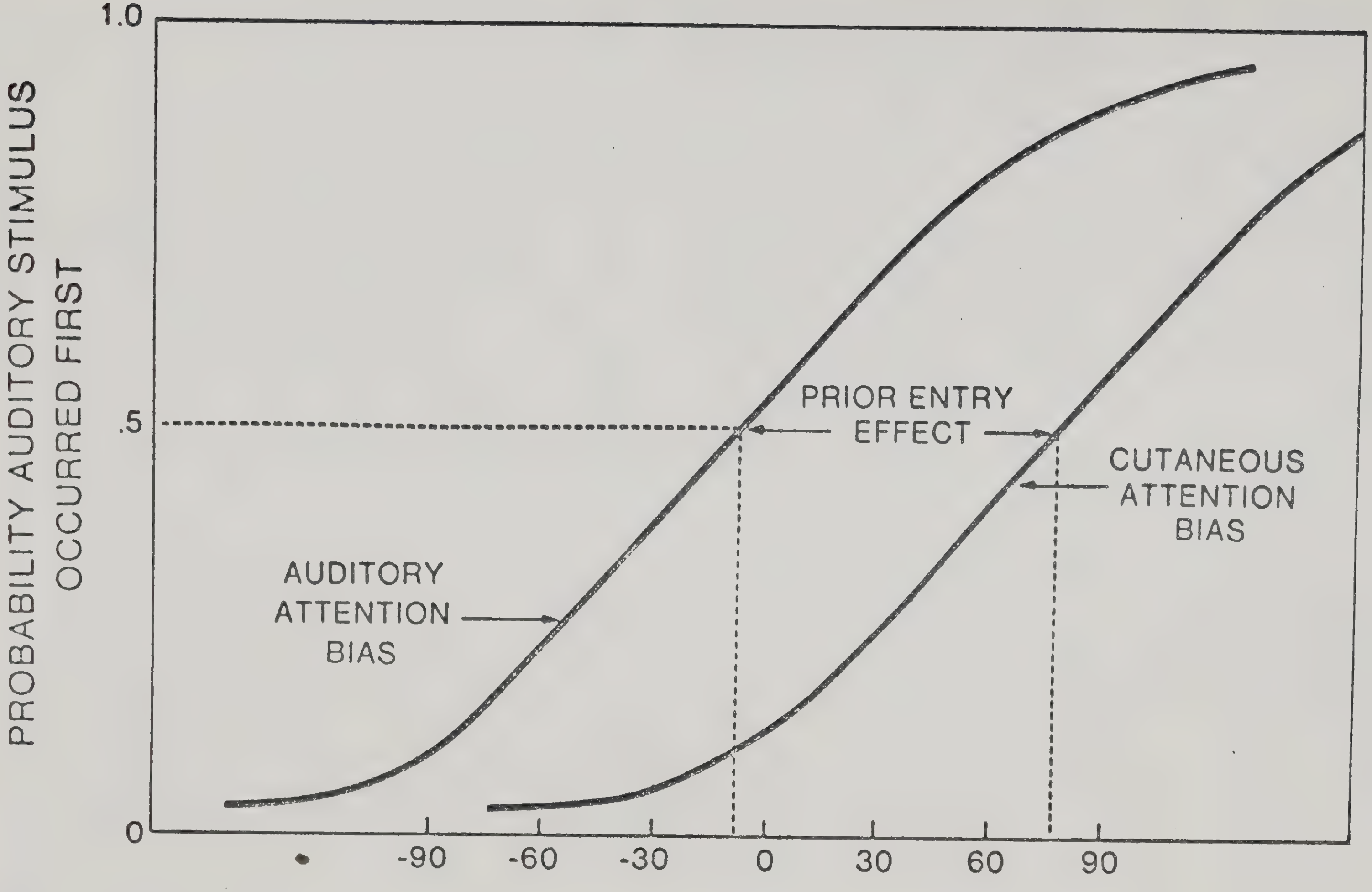


Figure 1. Idealized Results of the Sternberg, et al (1971) Prior Entry Investigation

effect was over 70 msec. In conjunction with the 50 msec effect found by Stone (1926), these data gave further support to Titchener's "law." Sternberg, et al. concluded by stating that ". . . the same stimulus pair can be consistently perceived in two different orders, depending on the state of attention (p. 12)."

In reviewing these studies, Frey & Wilberg (1975) noted that the subject pool from which the prior entry "law" had been tested and confirmed was meager and very homogeneous. In the relevant prior entry studies, a significant proportion of the subjects were either the experimenters themselves or their students, who were possibly acquainted with the prior entry law that they were testing. These investigators hypothesized that the basis of the doctrine's validity might rest upon the *a priori* knowledge of the "law" and the subsequent expectations of the performer. To test this hypothesis, naive subjects with no experience in psychomotor experimentation, as well as no *a priori* knowledge of the doctrine of prior entry, were used to replicate the Sternberg, et al. (1971) study. A comparison of the results of the two experiments is given in Figure 2. The separation of the modality biased curves that is predicted by the prior entry hypothesis is not evident in the Frey & Wilberg study. In fact, there is virtually an overlap of the functions across the entire ISI range, despite induced attentional locus. In view of these results, Frey & Wilberg (1975) concluded that the attentional focus of the performer did not affect temporal order resolution. As such, Titchener's "law" was tentatively dismissed as an artifact of the *a priori* knowledge and expectations of subjects in the earlier investigations.

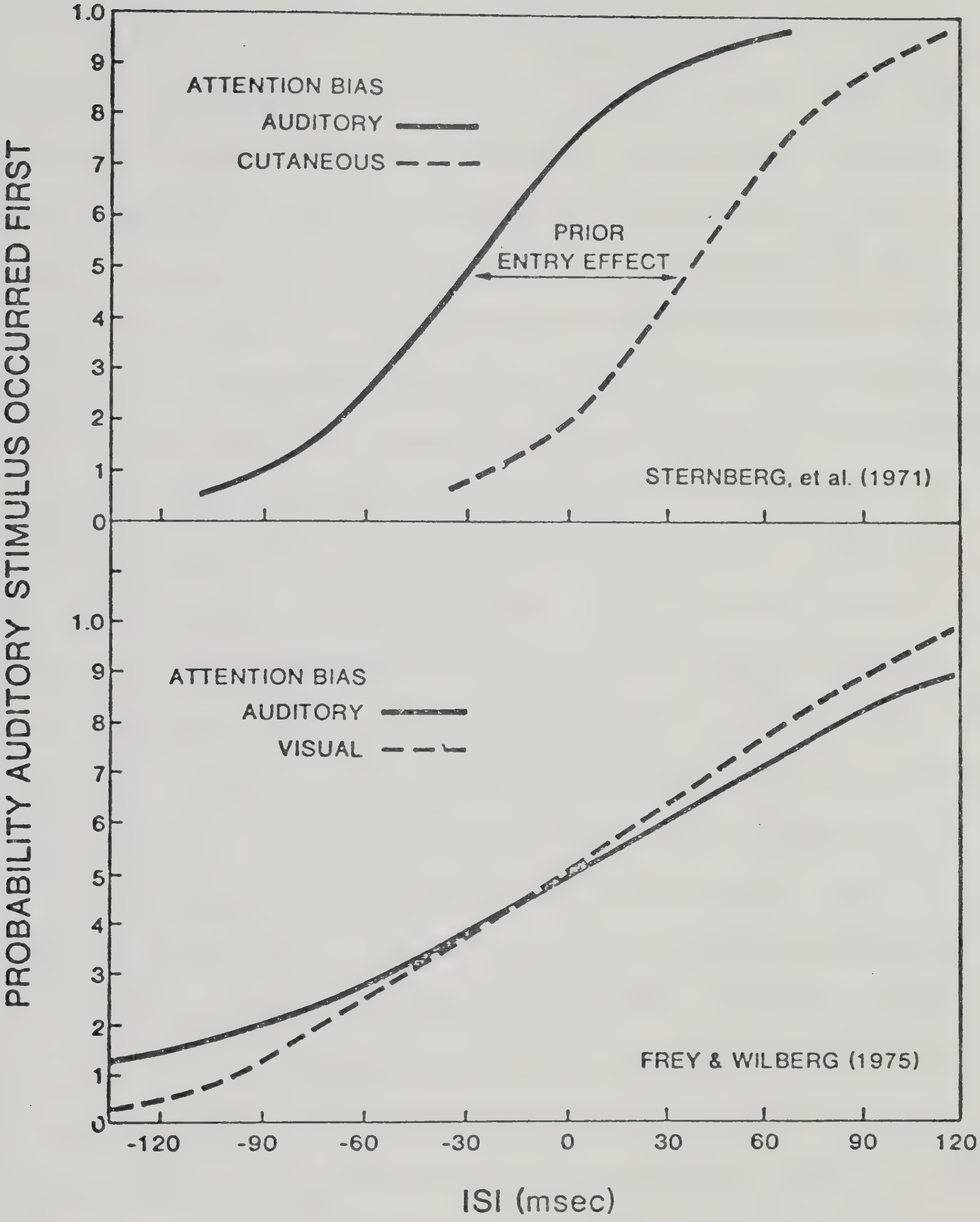


Figure 2. Comparison of the Results of the Sternberg, et al. (1972) and Frey & Wilberg (1975) Prior Entry Investigations

Vanderhaeghen & Bertelson (1974) had previously undermined the prior entry hypothesis by providing data which implied that selective preparation to give a fast identification to one particular stimulus did not necessarily affect the apparent time of occurrence of that stimulus. However, the most damaging evidence against the law of prior entry has been given by Cairney (1975a). Using signal detection measures, Cairney showed that when attention was directed to one member of a pair of near-simultaneous signals, there was no tendency to perceive the attended signal as occurring relatively sooner. His methodology required subjects, naive to the prior entry hypothesis, to make decisions about the sensory characteristics of one of the two signals employed. In the auditory-bias condition, either a high or low frequency characteristic of an auditory signal had to be identified prior to the TOJ. In the visual-bias condition, a judgment as to the length of right and left oscilloscope generated lines was required prior to the order judgment. Despite the fact that attention was biased to either the auditory or the visual signals in separate experiments, no evidence of a preponderance of either "attended" signal being judged as occurring relatively sooner occurred. More recently, Cairney (1975b) has provided further evidence contrary to the law of prior entry by experimenting with the complication clock apparatus of the 19th century investigators. In this final study, he suggested that the classical "anti-clockwise" errors that were the basis of Titchener's formulation of the prior entry law were caused by the particular characteristics of the task and apparatus. This point of view strongly resembles the attack on the usage of the complication clock by Dunlap (1920) and the

proposition by Geiger (1902) that the "negative error" phenomenon was actually due to locational peculiarities of the apparatus and the human oculo-motor musculature.

In summary, the early experimental literature has been supportive of the doctrine of prior entry while the later experimentation in this area has tended to discredit its validity. Because of the fact that the law had been tested under varying experimental paradigms and methodologies, however, an unequivocal decision concerning the validity of the prior entry phenomenon has been relatively untenable.

ATTENTION

All research in the area of human performance is concerned with the capabilities and limitations of the human operator. As such, human performance theorists are necessarily interested in theoretical models of human behavior that have been generated in the complimentary disciplines of acoustical research, verbal and motor learning, human factors and control theory engineering, and experimental, neurophysiological and cognitive psychology. This study concerns itself with the effect of attention upon the temporal order judgment capabilities of the human performer. The overt response of subjects is mediated by processes that occur from the moment that a relevant environmental change is detected until the effector mechanism is given a response directive. Along this time line of processing stages, the role of attention has been implicated in a number of provocative theoretical views of "man." A review of the more salient models of the human performer describes attention as a conspicuous variable in each and every hypothesized process

from sensory stimulation to response. Attention has been implicated, by the doctrine of prior entry, to be a principal determinant of the psychological phenomenon of temporal successiveness and simultaneity. By examining current models of human performance it may be possible to gain a greater insight concerning the nature of attention, its role in response execution, and its effect upon the judgment of temporal order.

To facilitate the review of current literature in attention, the human operator will be considered an information processor as represented by the simple model in Figure 3. In this view, theories of attention that affect the "input side," (ie. stimulus encoding, perception, pattern recognition, etc.), will be distinct from theories affecting the central processor (ie. recoding, subjective organizational strategries, etc.), and models of attention affecting the "response side," (ie. decoding processes, response organization and initiation, etc.). In this way it may be possible to infer distinct causal implications for attention in each of these stages of information processing.

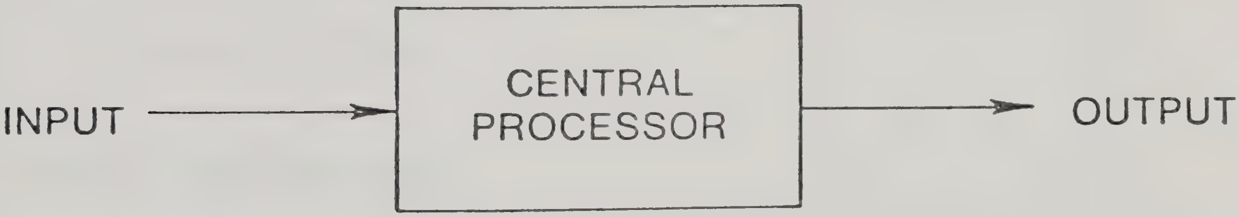


Figure 3. An Information Processing Model of the Human Operator

Several theorists have described the different connotations that the construct "attention" may be ascribed. Berlyne (1969) has categorized attention as either intensive (the general arousal of the organism) or selective (the narrowing of sensory input that controls subsequent behavior). Similarly, Posner & Boies (1971) have described attention in terms of arousal, selection, and limited capacity models. Moray (1970) also describes a number of different meanings for the concept of attention as does Treisman (1960). Consistent among each of these conceptualizations is the description of an attentional mechanism that can focus the effort of an organism (see Kahneman, 1973), in such a way that a determination of which sensory input will subsume responses and which portion of the sensory milieu will be providing the necessary information for further action, can be effectively obtained. This characterization of attention is its selective nature, and will be considered further as the operator's ability to differentially treat sensory, perceptual, centrally-processed, or response-oriented information. The following theories are a review of recent theoretical considerations of selective attention; why it exists, how it works, and where and when simultaneous and closely successive sensory events may be differentially treated.

Afferent Neural Inhibition

In a left-to-right model of information processing (Figure 3), the first effect that a consciously directed focus of attention upon a certain input might produce is an actual attenuation of the afferent neural information of unattended stimuli. Physiologically this implies an

inhibition, attenuation, or complete blocking of the synaptic transmission of sensory information travelling the afferent pathways from sensory receptor surfaces to higher centers of the central nervous system. The best known investigations underlying this hypothesis have been cited by Hernandez-Peon and co-workers (Hernandez-Peon & Scherrer, 1955; Hernandez-Peon, Scherrer, & Jouvet, 1956, 1957). Electrophysiological evidence by these researchers showed that a behavioral shift in attentional focus to a modality-specific stimulus caused a drastic reduction in evoked potential amplitude in unattended channels. These results supported a "gating" or sub-cortical control function of attention. Despite some favorable reviews of Hernandez-Peon's results (see Meldman, 1970), current theorists in the study of the neurological aspects of attention are not in favor of the peripheral gating hypothesis. The primary reason for this is the fact that the Hernandez-Peon, et al. results have not been successfully replicated. As an example, in attempting to verify an acoustical dampening of the cochlear nerve response in humans, Picton, Hillyard, Galambos, and Schiff (1971) found that while a nonspecific acoustical evoked potential and the contingent negative variation were sensitive to experimental manipulations, neural transmission in the auditory nerve was unchanged by the subject's attention. One of the strongest indictments against the peripheral gating hypothesis is by Worden (1966). The thrust of his criticism rests upon the fact that the auditory potential was affected by unrelated and uncontrolled methodological artifacts. Such criticism has recently labeled the peripheral gating hypothesis as "psychologically naive" (Walley & Weiden, 1973). The validity of any

sub-cortical "gating" mechanism of attention is dependent upon two crucial variables. The first is the control of the actual attention of the subject, the second is the neurophysiological indicant of peripheral suppression. Peripheral gating theory has depended primarily upon the circular argument that a reduced neural impulse implies a subjective state of inattention, while attention is paramount to an amplified evoked potential. The assumption that potential amplitude is correlated with attention may be argued based upon the fact that there is a lack of evidence that the evoked potential to a signal is increased in amplitude when the stimulus is being perceived (Horn, 1965). More recent evidence by Boddy (1973), using reaction latencies as the dependent variable, would also support the notion that potential magnitudes may not always correlate positively with the subject's state of attention. In that study, faster reaction times were correlated with reduced evoked potential amplitude. If it is assumed that attention directed to a signal reduces, or at least stabilizes, reactions to the attended stimulus, Boddy's results raise questions about the relationship of evoked potential amplitude and attention. As such, the peripheral gating hypothesis may not have been given as robust an experimental treatment as may be required to validate or refute it; a different dependent variable may be required to fully test the theory. Until a more appropriate metric is employed and, in view of the lack of support that the peripheral gating hypothesis has received, however, it may be tentatively rejected as a viable consideration in current attentional theory.

Differential Processing of Attended Information

Selection before processing

With the rejection of a peripheral attenuation or blockage of neural input, the next possible locus of attentional "control" of information is prior to perception, after simultaneous inputs have contacted short term sensory store (see Sperling, 1960), and there has been a junction with working or operational memory, hereafter referred to as short term memory.

The most famous of the informational processing views of "man" was given by Broadbent (1958). In his model of human performance, attention served as a mechanism whereby irrelevant stimuli were filtered by a pre-set criterion, perception occurring only after relevant sensory information passed the filter and obtained access to a central processing unit. Filter theory, as it became known, was discredited by results of studies which showed that subjects were capable of perceiving information on channels that they were not attending (Moray, 1959; Treisman, 1960; Gray & Wedderburn, 1960). To salvage the filter model, which seemed to be a viable explanation of attention except for this discrepancy, Treisman (1960) suggested that incoming stimuli in an "unattended" message were not completely disregarded but were rather attenuated. Thus stimuli on the irrelevant channel in a dichotic listening task may be perceived if the threshold for activating the "dictionary units" in memory for the particular stimuli have a relatively low threshold. Filter theory, after Treisman's contribution, became known as filter-attenuation theory. In summary, it hypothesizes that simultaneous inputs are not perceived unless they pass through a pre-set filter or

have a low threshold for perception by nature of some relevance to the organism (Broadbent, 1971).

The filter-attenuation model suggests that attention must precede perception. If sensory information fails to pass the filter, it remains in short term store until the processing unit is clear. This implies that information may be stored in short term storage before it has been consciously perceived. When the processor is clear, the stored sensory information may then be processed and subsequently reach conscious awareness. Such a theory would support, or lend credence to the prior entry hypothesis. The unattended signal in a dual stimulus ensemble would only be processed as soon as the attended signal was free of the processor. As such, it may be argued that the unattended signal would be consciously perceived as having occurred after the attended or predisposed stimulus.

Selection after processing

Filter-attenuation theory implies that only those inputs which have successfully passed the filter, or have an exceptionally low threshold for perception, reach the processing unit for further analysis. Deutsch & Deutsch (1963) proposed another explanation for the experimental results that had been generated in the studies which had led to the filter-attenuation model. These theorists suggested that all inputs reach the central processing unit in parallel, with a differential treatment of signals depending upon the heaviest weighting of significance determined by momentary intentions or habituated disposition. This analysis is considered preconscious: those inputs which carry the

greatest significance fire recognition units in the "dictionary" and are thereby perceived. Norman (1968), in a theory which closely resembles the Deutsch & Deutsch (1963) model, proposed that momentary intentions and lasting dispositions determined preset weightings of significance associated with the parallel activation of simultaneous inputs. These weightings were termed "pertinence" and it was the combination of an input's pertinence with its sensory influence which determined which signals reached awareness and dominated perception and memory. Both the Deutsch & Deutsch and Norman hypotheses of selective attention accommodate the prior entry hypothesis. If the significance or pertinence of an attended input is more heavily weighted than an unattended signal, the attended or predisposed stimulus would reach conscious awareness first and therefore be judged as occurring before a closely-successive or simultaneous input which was in an unattended channel.

Analysis by synthesis and expectation

Neisser (1967), having rejected the "negative" aspects of filtering and attenuation, contended that "irrelevant" stimuli were neither filtered out nor attenuated but rather "fail to enjoy the benefits of analysis by synthesis (p. 213)." Neisser suggested that selective attention consisted of the allotment of a limited processing capacity to the analysis of chosen stimuli and to the formulation of chosen responses. Underlying this hypothesis is a passive system operating below consciousness which groups and organizes sensory data prior to any conscious attentive processes. These pre-attentive processes are responsible for maintaining the features of stimulation to indicate any

necessary redirection of focal attention. Neisser suggested that perceptual analysis assumes selective attention and that this focused attention assumes awareness. Kahneman (1973) has deemed this unlikely since complex psychomotor skills are often performed with little awareness although they demand extensive perceptual analysis. Avoiding this criticism, Hochberg (1970) has described a difference between perceptual analysis and conscious awareness. Awareness, according to Hochberg, will occur only if what is perceived has an association stored in memory. Perception, therefore, is described as the verification of a set of expectations stored in memory; with the assumption that only prior-verified sets of expectations are stored. Both of these models are closely related. For Hochberg, any stimulus which is not matched to its prior expectation in storage will be bypassed and forgotten, unless of course it has a significant relationship to the present task. For Neisser, the analysis by synthesis is quite similar to the production of the stored expectations in the Hochberg model. Again, the prior entry hypothesis may be accommodated. In both models, despite the fact that Hochberg attempts to differentiate between perceptual analysis and conscious awareness, the conscious perception of inputs is based upon the processing of chosen stimuli, the choice depending upon the relevance of the signals for active construction or synthesis (Neisser, 1967) or the matching of expected stimulation (Hochberg, 1970). Both theories might conceivably predict that an attended signal would certainly attain conscious awareness in preference to an input, or at least prior to an input, that was not relevant to an analysis by either synthesis or expectation.

Post-perceptual theories

In all of the theoretical hypotheses of selective attention so far discussed, the locus of attentional control has been postulated to take place before perception or awareness. In other words, to selectively attend to a relevant signal has meant that sensory information, filtered, attenuated, synthesized or expected, has been selected for processing which has allowed for the perception of the selected signal to occur. In summary, attention was the prerequisite for perception. It may be argued, however, that perception occurs prior to attention. Evidence accumulated in studies of the orientation reaction (Lynn, 1966) and anecdotal evidence as well, supports the notion that an unattended signal may, depending on variables such as surprise, conflict, or intensity, attract attention. Norman (1968) has suggested that there must be some perception of "irrelevant" information so that the human operator knows whether to switch attention or not. Neisser (1967) alludes to the same point when he speaks of pre-attentive processes that organize a stimulus ensemble before inputs can be subsequently analyzed. For Norman, a pre-attention mechanism analyzes all sensory information to some extent, a point of view contrary to the single channel hypothesis originally suggested by Broadbent (1958). Based upon a large body of conclusive evidence, Keele (1973) has suggested that memory activation of sensory information is an automatic process acquiring no allocation of attention. In Keele's theory of attention demand, only processes subsequent to memory activation require attention and are therefore mutually interfering. Important in the Keele model is the question of when conscious awareness occurs. Keele states

that simultaneous signals activate memory representations in parallel, and that mental operations can be performed on such information at the sensory level, before memory activation, or at the actual level of memory activation. This point of view implies that conscious awareness of sensory information (ie. perception) is possible before attention is required or necessary. Evidence for this conclusion is provided by Posner & Mitchell (1967) who reported that subjects were capable of making perceptual judgments based solely upon sensory information, prior to any memory activation whatsoever. At this level of information processing, perception of stimulus events occurs prior to the locus where attention is required, namely subsequent to memory retrieval. In many respects a theory proposed by Reynolds (1964, 1966) as an explanation of the psychological refractory period (see Smith, 1967, for an overview), is quite similar to Keele's attention demand hypothesis. Reynolds, basing his conclusions on the increasing reaction time to a second signal in a psychological refractory period, dual-stimulus reaction time paradigm, reported that it was the interference between two stimuli at a response selection stage of processing that gives rise to the refractory phenomenon. To Reynolds, all processing prior to response organization is orthogonal and parallel. Selective attention in the Reynolds' theory was necessary at the response initiation phase of information processing where a phenomenon termed the "temporary inhibition of response" occurred. While Reynolds' model may not be considered an actual theory of selective attention, certain premises underlying his description of the human performer are relevant to the present discussion. Of primary interest is the hypothesis that the interference

in processing simultaneous tasks occurs in the response organization phase of information analysis. If this is true, and evidence which assigns interference in processing multiple signals to an inability in initiating independent responses would suggest it is (Keele, 1970), then the selective allocation of attention is certainly not implicated in processes prior to response initiation. Both Keele (1973) and Reynolds (1964, 1966) have provided theoretical frameworks that suggest the parallel processing of competing stimuli up to at least memory retrieval and response initiation, respectively. Constrained within these hypotheses, the prior entry doctrine would not be supported. The biasing of attention to one of two signals should not affect the memory activation and hence perception of the temporal order of occurrence of closely presented stimuli. Whereas neither theory addresses itself to the question of attentional effect upon temporal perception, should attention be focused upon one or the other of the signals, assuming the human operator has the structural precision to process the successiveness of the stimuli, there is nothing to predict that selective attention to either signal should in any way bias the automatic process of perception.

Capacity models

The models so far surveyed have described "man" as a limited capacity channel with a fixed capacity. Moray (1967) has suggested instead that the human operator is a limited capacity processor. This theory contends that instead of explaining performance limitations in terms of structural bottlenecks, ongoing tasks themselves determine what

can be processed simultaneously. In this theory, man's attentional behavior is not viewed as a transmission line of limited capacity which is a passive carrier of messages, but rather as a central processor of limited capacity which receives, transforms, and generates messages. Similarly, Kahneman (1973) has suggested a theory of attention based upon effort. This theorist, like Moray, suggests that there is a general limit on man's capacity to perform mental work and that this limited capacity may be allocated with considerable freedom among concurrent activities. Kahneman's model hypothesizes that any number of activities may be made to occur by an additional input of attention or effort from the limited capacity. If there is spare capacity there is no interference between tasks; however, when the supply of attention does not meet the demands of the concurrent activities, performance falters or completely fails. The capacity models of Moray and Kahneman suggest that there may or may not be a prior entry effect depending upon the available capacity of the operator. Kahneman's contention is that the number of activated recognition units in memory and the degree of their activation are affected by the amount of attention paid to a stimulus. In this regard, the capacity models may predict a prior entry effect if attention is biased toward one signal to such an extent that the available capacity is exceeded. If this were the case, Kahneman has suggested that an attended stimulus will "...have prior entry, ie. it will appear to have occurred sooner than a physically simultaneous unattended stimulus (p. 193)."

Gnostic unit activation

In reviewing one final theory of attention, Walley & Weiden (1973) have presented a neurophysiological model which attempts to explain the actual physiological mechanisms underlying selective attention. Using the term "lateral inhibition," these researchers suggest that when sensory input activates cell units in cortical regions, nearby cell units are inhibited. Walley & Weiden call these cell groupings gnostic units (after Konorski, 1967), and the inhibition of nearby gnostic units is a process called "cognitive masking." It is cognitive masking that gives rise to the behavioral experience of "attending" to a specific task. In a reply to criticism by Feeney, Pittman, and Wagner (1974), Walley & Weiden (1974) clarify a position that is relevant to the prediction of their theory regarding a prior entry effect. Walley and Weiden write, "...stimuli which do not excite activity in the same gnostic fields should be encoded simultaneously with little interference (p. 541)." In addition to this statement, these authors augment their position by citing studies by Treisman and Davies (1973) and Rollins and Thibadeau (1973) which reported increased interference between stimuli simultaneously presented within the same modality and little or no interference in inter-model stimulus presentations. The prior entry hypothesis is based upon the interaction of selective attention with stimuli in different sense departments. In this regard, the Walley & Weiden theory of lateral inhibition would not predict that attention to one signal should affect the order perception of two closely-occurring heteromodal stimuli.

Perceptual reliability

Paramount in the discussion of prior entry prediction within the framework of the attentional models cited above, has been the untested assumption that decisions concerning temporal order are based solely upon the time of perception of signals. Regardless of whether it is the difference in perception of the signals themselves or if the percept of each signal contacts a type of temporal order decision center (Sternberg & Knoll, 1973), this assumption holds that once perception occurs, the operator need only "read off" the order information, with no subsequent voluntary or automatic processing of the perceptual trace required. This assumption in no way undermines the prior entry hypothesis that attention to a signal biases temporal order judgment. Rather, it merely emphasizes that whether or not attention biases temporal order judgments depends upon whether attention biases the operator's perception. In other words, attention is only a variable of interest until perception occurs; the subject is considered reliable in transmitting his perceptual experience, without any "load" upon either the memory system or further processing mechanisms.

SUMMARY

The early experimentation which led to the implication of attention in subjective temporal perception has been reviewed. The explanation for the negative errors in the complication clock studies presented by Titchener (1908) in the form of the doctrine of prior entry, and its subsequent experimental support in discrete dual-stimulus presentations was discussed. The recent work by Sternberg, et al. (1971)

in reexamining the prior entry hypothesis and providing evidence which supported it, as well as the negative evidence provided by Frey & Wilberg (1975), Vanderhoeghen & Bertelsen (1974) and Cairney (1975a, 1975b), has been reviewed. Structural and capacity models of attention were discussed. The models of Broadbent (1958, 1972), Treisman (1960), Deutsch & Deutsch (1963), Norman (1968), Neisser (1967) and Hochberg (1970) predict a prior entry effect given that required attentional conditions are met. These models contend that attention is required before perception can occur. The hypotheses presented by Keele (1973) and Reynolds (1964, 1966), however, do not support a prior entry hypothesis due to the fact that these models suggest that attention is necessary only for processes subsequent to memory retrieval or response initiation, respectively. No interference is assumed for perception which involves processes occurring before these stages. The models of Moray (1967) and Kahneman (1973) were reviewed and suggest that any and all tasks may be mutually interfering if available attention is exceeded. The capacity model predicts a prior entry effect, therefore, if attention is sufficiently biased to one signal such that there is no available capacity to process the other stimulus simultaneously.

Finally, the neurophysiological theory of Walley & Weiden (1973), in explaining how the lateral inhibition of gnostic units in association cortex leads to "cognitive masking" and selective attention, supports the position that the perception of heteromodal signals should not be disrupted by the attentional focus of the operator. Gnostic unit activation is hypothesized in the theory to inhibit only closely associated (by location) gnostic units. In this regard, inter-modal

stimulation should fire locationally different gnostic units which should rise to conscious awareness in parallel.

The assumption that the operator's judgment of temporal order is based upon the time of perception was discussed. The critical question is whether or not attentional focus biases perception; the fidelity of the subject in transmitting the perception is considered reliable.

CHAPTER III

METHODOLOGY AND RESULTS

Experiment I

METHODOLOGY

Purpose

Recent studies by Vanderhaeghen & Bertleson (1974), Frey & Wilberg (1975), and Cairney (1975a, 1975b) have provided evidence contrary to the prior entry hypothesis. Unfortunately, neither of these experiments attempted to test the law within the same methodological framework as that employed by Sternberg, Knoll, & Gates (1971) who, to date, have provided the most compelling evidence that prior entry is a valid perceptual phenomenon.

The purpose of Experiment I was to repeat the study by Frey & Wilberg (1975) with different, but perhaps crucial, methodological changes. The findings of Sternberg, et al. (1971), which gave credibility to the doctrine of prior entry, were not obtained in the Frey & Wilberg study. The negative prior entry finding, however, was confounded with three methodological differences between the two studies. The first was the fact that reaction time performance in the Sternberg, et al. study was rewarded. The second was that these same researchers presented a cue stimulus, similar to the primary signal, with a duration of approximately 500 msec prior to the onset of the stimulus ensemble. The third difference was that catch trials were more frequent in the Sternberg, et al. study than in the Frey & Wilberg investigation.

The Frey & Wilberg study showed no effect of attentional bias on temporal order perception. These investigators hypothesized that the a priori knowledge of subjects in the earlier studies was responsible for the previously reported prior entry effect. Because no prior entry effect was evidenced in the Frey & Wilberg study, which used subjects naive to the prior entry doctrine, these researchers felt that an a priori knowledge explanation was adequate. However, in view of the methodological differences between the Frey & Wilberg study, which showed no prior entry effect, and the Sternberg, et al. study, which evidenced a large prior entry effect, the Frey & Wilberg conclusion has recently been viewed with suspicion. It is quite possible that attention was more adequately biased in the Sternberg, et al. study due to the fact that, with a cue before stimulus presentation, the perceptual mechanism subserving detection of the primary signal was "primed," possibly with a concomitant increase in subjective expectation. Such a point of view is supported by the notion that a cue brings an expected stimulus out of storage and into a state of high availability (La Berge, 1971). Experimental evidence in choice reaction time experiments (see Hinrichs & Krainz, 1970), shows that subjective expectation influences speed of reaction. This supports the point of view that the lack of using a cue in the Frey & Wilberg study may account for less than a complete attentional bias toward the primary signal and hence a failure to produce a prior entry effect. This argument rests upon the assumption that expectancy and attention are highly correlated; a point of view underlying Hochberg's (1970) theory of attention and one which may be tentatively accepted given the fact that, even in Titchener's (1908)

classical description of the prior entry effect, he discusses "the stimulus which the subject is predisposed to perceive"; predisposition being synonymous with expectation.

By providing reaction time feedback, Sternberg, et al. may have induced an even greater attentional bias toward the primary signal. Because knowledge of results (KR) was not given for TOJ performance, subjects may have considered the reaction time task as the more important of the two. This would seem especially probable in that Sternberg, et al. rewarded their subjects for reaction time performance that exceeded "deadlines." No KR nor reward was provided for accuracy of temporal order judgments.

The ratio of catch trials to non-catch trials may also have been an influencing factor in the attentional focus of subjects in the two studies. In the Frey & Wilberg study, subjects erroneously reacted 23 times of the 240 catch trials presented, for an error rate of 9.5%. Although Sternberg, et al. did not report any catch trial information, it is likely that the greater percentage of catch trials in their study (50% of all trials were catch trials) did not surprise or "catch" their subjects to the same degree that a lower frequency of catch trials (9% of all trials were catch trials) "caught" subjects in the Frey & Wilberg study. Sternberg, et al. did not report any actual reaction time data but it is expected that with the high ratio of catch trials, their mean reaction time performance was slower, with an accompanying reduction in false alarms or reactions to catch stimuli. On the other hand, due to a lower representation of catch trials, the reaction time performance in the Frey & Wilberg study would likely be faster but with a greater percentage of errors.

Experiment I addressed itself to the confounding of methodological differences between these recent studies investigating the prior entry hypothesis. If, despite modifying the Frey & Wilberg methodology, there remained no change in the failure of the subject's attention to bias his order perception, then the postulated a priori hypothesis or perhaps some post hoc non-prior entry explanation would be supported. If, on the other hand, the data reflected the results obtained by Sternberg, et al., the doctrine of prior entry would receive the necessary sustenance needed for continued longevity.

Dependent Variables

The dependent variables in this experiment were reaction time and temporal order judgment performance. To ensure that an attentional bias was maintained in the TOJAUD and TOJCUT conditions, reaction performance in the Donders' (1868) c-type reaction with TOJs required (the TOJRT condition) were required to remain stable and in correspondence with reaction time performance when no TOJ data was concurrently required (the CMPRT condition). The mechanics of the up-and-down staircase procedure (see Procedure section below) insured that RTs in the different attentional conditions were optimally stable. By introducing a payoff incentive for fast reaction time performance, this stability was anticipated. The TOJ ability of subjects was then comparable for different attentional biases, including the TOJNO condition when no experimentally induced attentional bias was involved.

Preliminary Procedures

Prior to the main experimental conditions, preliminary procedures were required. The first of these was the collection of simple reaction time data for each modality. The methodology was modeled after classical Donders' (1868) a-type procedure. These data were used to compute base line reaction time performance which was necessary in analyzing CMPRT and TOJRT stability and, more importantly, to assure familiarity with the reaction time apparatus.

At the start of each experimental session, subjects were required to make a cross-modal match for intensity between an invariant 72 db SPL burst of white noise and the cutaneous signal, mild electric shock to the forearm of the non-dominant arm. This procedure was necessary to avoid, or at least minimize, the use of unnecessary operational strategies based upon the subjective perception that signals were not of equal strength. This procedure was employed before both the CMPRT and TOJRT conditions.

Experimental Design

Due to the nature of the up-and-down staircase procedure of adjusting ISIs in the TOJRT condition (see Procedure section below), an analysis of variance between CMPRT and TOJRT conditions was unnecessary. The TOJ from trial to trial was only considered if the reaction time associated with it was faster than one standard deviation above the related CMPRT mode. In this sense, reaction time data in the TOJRT conditions were not truly of experimental interest in that only those reaction time data exceeding the one standard deviation "deadlines"

were recorded. This design ensured that the TOJ data were as true a reflection of an attentionally biased state as possible.

The examination of TOJ bias under the different conditions of attentional bias utilized a subjects by treatments repeated measure design. In this mixed factor design subjects were considered random and treatments were considered fixed. The PSS, or 50% point of the psychometric functions, of each condition for each subject was the relevant datum for an analysis of variance (ANOVA). This design incorporated a variant of the t test in determining the F ratio (Edwards, 1972) and its rationale is explained in Appendix 1. In addition to the two-treatment ANOVA, within-subject data were individually plotted in accordance with methodological procedures introduced by Sternberg, et al. (1971).

Task

The experimental task was identical to that of Sternberg, et al. (1971) as described in the literature review in Chapter II.

Apparatus

All experimentation was undertaken in the Human Performance Laboratory in the Faculty of Physical Education at the University of Alberta. The auditory white noise stimulus was provided by a General Radio Company type 1390-B random noise generator and delivered via headphones at 72 db. Sound pressure accuracy was obtained by calibrating the auditory output with a Dawe Instruments model 1400G sound level meter. The cutaneous signal was provided by an Applegate model 228

shock stimulator and delivered via copper electrodes to the hairless underside of the forearm of the non-responding limb. The center of the more distal of the 5/8-inch diameter electrodes was placed one inch from the base of the palm in line with the insertion of the flexor carpi radialis muscle. The second electrode was positioned between 3/4 and 1½ inches more proximally than the first electrode. The reference cutaneous experience was a mild vibratory sensation that extended proximally along the radius to the brachioradialis muscle belly. Due to individual differences in skin conductance, the distance between electrodes was variable from subject to subject in order to obtain a subjectively similar vibratory stimulus experience. Once determined, a Lafayette two-point aesthesiometer insured accuracy to one millimeter in determining electrode placement, so that the exact location of electrodes remained constant for each subject throughout the experiment. The sequencing of warning signal, cue signal, and response stimuli was controlled by a series of Hunter Manufacturing Company Model 100-C, series E Decade Interval Timers. Reaction time was recorded on a Hunter Model 120-C Klockounter with digital readout capability. A series of relays and momentary switches completed the circuitry. All stimulus generating apparatus as well as the experimenter were located outside of a dimly-lit, sound-attenuated experimental room. Wiring to the subject was completed through a patch panel behind the reaction time apparatus, which was a Burgess Products Company reaction time switch mounted in the vertical plane. A 24 cm by 13 cm plywood platform raised 9 cm by pegs on the far side housed the switch and allowed the subject to comfortably rest the responding hand while initiating responses. The

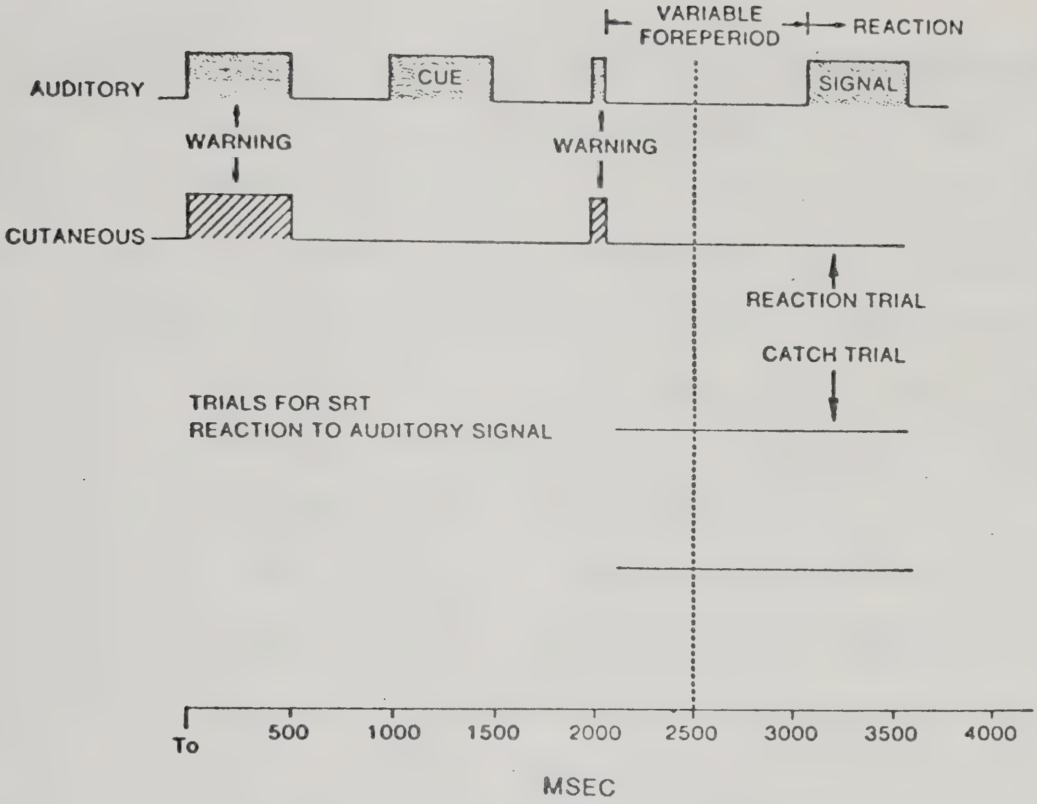
vertically mounted reaction time switch provided a 3 cm lever requiring 3 millimeters of throw and less than 50 grams of force to close. Subjects closed the switch by flexing the index finger of the responding hand. After making a reaction time response subjects indicated TOJ information by depressing one of two microswitches located to the right of the reaction time lever labeled respectively "EAR" and "ARM" which energized a light on the experimenter's console relaying the subject's choice.

Subjects

Subjects were six unpaid, volunteer graduate students in physical education at the University of Alberta. All subjects were right handed, had no previous exposure to psychomotor learning experimentation, and had no *a priori* knowledge of the law of prior entry.

Procedure

Instructions were delivered via tape recording to ensure uniformity of presentation. The exact instructional information for each condition is contained in Appendix 2. Prior to any experimentation, a cross modality intensity match was made as described above under preliminary procedures. In the SRT condition, subjects were given five practice trials to gain familiarity with the reaction time device and the warning signal schema, and then twenty reaction time trials in one of the modalities. The sequence of catch and reaction trials is diagrammed in Figure 4. On a random half of all trials no reaction stimulus was presented. This procedure was utilized to familiarize


VARIABLE FOREPERIOD
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WARNING
WARNING
CUTANEOUS
REACTION TRIAL
CATCH TRIAL
TRIALS FOR SRT
REACTION TO AUDITORY SIGNAL
To
500
1000
1500
2000
2500
3000
3500
4000
MSEC

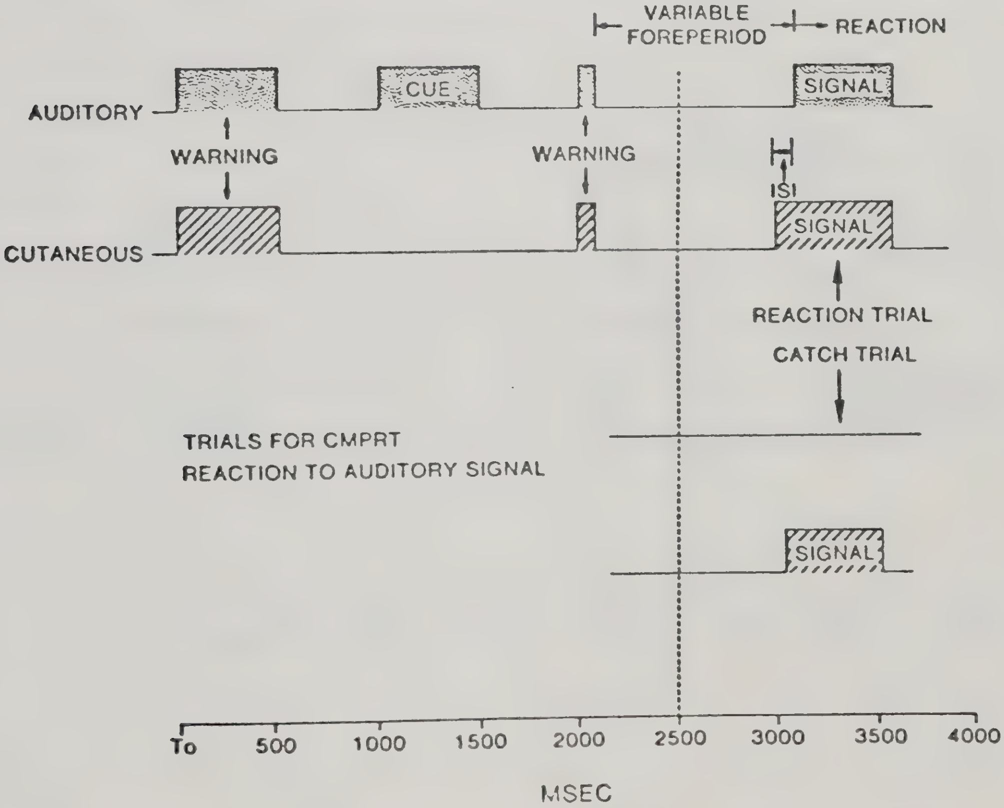
Figure 4. Reaction time paradigm for SRT condition

the subjects with the catch trial nature of the reaction time task to be employed in the CMPRT and TOJRT conditions and to minimize the strategy of responding to a subjective time estimation of the maximum foreperiod duration. The range of the foreperiod interval was 500 msec minimum to 1000 msec maximum. These were the same values employed in Sternberg, et al. (1971) as related by Sternberg (1976). The first bi-modal warning signal and the primary stimulus cue signal were presented for 500 msec. The second warning signal was 40 msec in duration. The variable foreperiod began at the offset of the second warning signal. The subject's response extinguished the stimulus and stopped the reaction time clock. No reaction time feedback was provided during the first block of 20 trials. After this initial block of trials, the

reaction time data were analyzed for mean and standard deviation statistics. This analysis took approximately five minutes and served as a rest period at the midpoint of the SRT session. During the next and subsequent blocks of 20 reaction trials, feedback was provided the subject. On trials in which the reaction latency was equal to or better than the mean of the previous block of scores, the experimenter verbally indicated such by the word "Good." On trials in which the reaction time was equal to or greater than one-half of a standard deviation faster than the mean of the previous block of trials, the experimenter responded with the word "Fast." On those trials in which the subject's response was equal to or greater than one full standard deviation faster than the mean of the previous block of trials, the experimenter said "Very fast." No response was given for those reaction times slower than the mean of the previous block of trials. This procedure was employed to emphasize the importance of speeded responses and to expedite an asymptotic SRT performance. No more than two 20-trial blocks of reaction trials were given per session. In this way, subjects were presented 85 trials per session: five practice trials, 40 reaction trials, and 40 catch trials. Subjects were required to provide SRT data until the t ratio between the means of consecutive 40-block sessions reached insignificance. Modalities were alternated from session to session and only one session was conducted per subject per day.

After an asymptote for each modality was obtained in the SRT condition, subjects were introduced to the CMPRT condition. The primary modality was selected at random and five practice trials were administered. Due to the difficulty of the CMPRT task, only 20 reaction

trials were administered per session. Thus only 45 trials in the CMPRT condition were required per session: five practice trials, 20 reaction trials, and 20 catch trials in which the auxiliary signal occurred alone. The paradigm for the CMPRT condition is given in Figure 5. When the response lever was pulled the entire stimulus ensemble was terminated. Only one CMPRT session was conducted per subject per day. Similar to the SRT condition the mean and standard deviation of the preceding block of 20 CMPRT trials for respective modalities were determined to provide reaction time feedback in the CMPRT condition. Between signal, inter-stimulus intervals (ISIs) ranged from -120 msec (cutaneous preceding auditory) to +120 msec (auditory preceding cutaneous). ISIs were randomly presented. As in the SRT condition, t ratios were computed for between block means to


VARIABLE FOREPERIOD
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CUTANEOUS
SIGNAL
REACTION TRIAL
CATCH TRIAL
TRIALS FOR CMPRT
REACTION TO AUDITORY SIGNAL
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To
500
1000
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Figure 5. Reaction time paradigm for CMPRT condition

determine significant differences. In this way, subjects were required to provide CMPRT data until the difference between the means of 20-trial blocks per modality were not significantly different.

When CMPRT performance reached a stable level, subjects were introduced to the TOJNO condition. The paradigm in this condition is represented in Figure 6. No reactions were required in the TOJNO condition and, as such, no cue signal was required. After the last bi-modal warning signal there was a variable delay and then both signals occurred at various ISIs. Unlike the CMPRT condition in which ISIs were presented at random within the range -120 to +120 msec, the TOJNO condition employed an up-and-down staircase procedure to change the ISIs from trial to trial (Cornsweet, 1962). A full explanation of the staircase method is given in Appendix 3. Basically the method adjusts

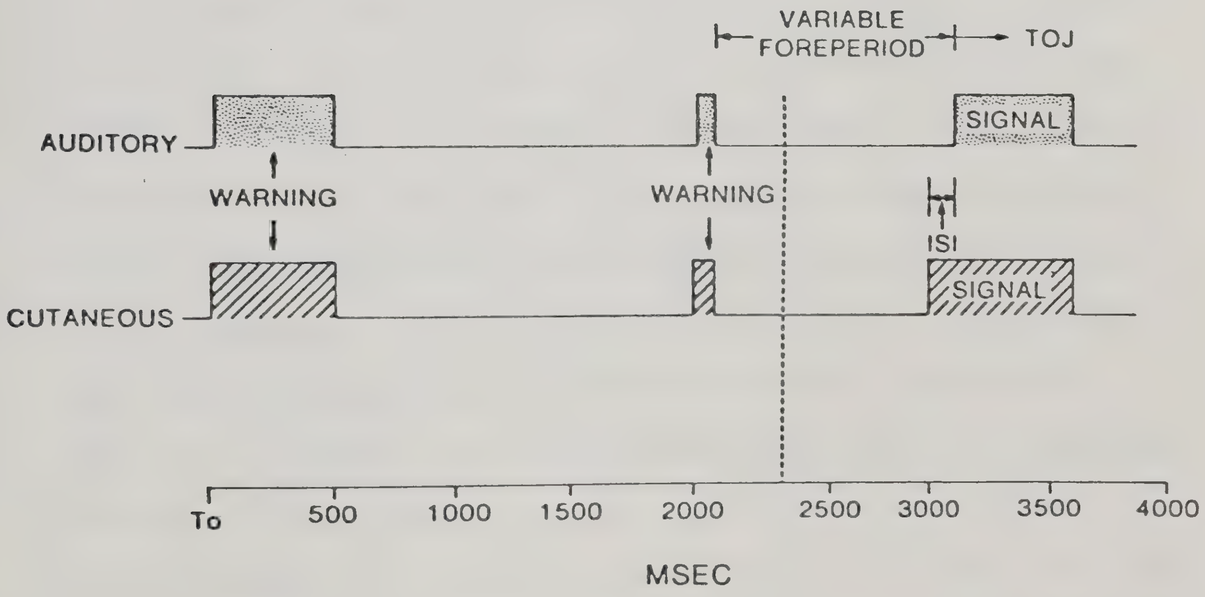

VARIABLE
FOREPERIOD
TOJ
AUDITORY
SIGNAL
WARNING
WARNING
ISI
CUTANEOUS
SIGNAL
To
500
1000
1500
2000
2500
3000
3500
4000
MSEC

Figure 6. Temporal order judgment paradigm for TOJNO condition

the ISI of trial n+1 based upon the TOJ of trial n. In this way, the subject's own responses cause the ISI distribution to center rather accurately around the PSS. In correspondence with Sternberg, et al. (1971), two 40-msec step interleaved staircases were employed in the TOJNO condition until a criterion of convergence was met. This criterion of convergence required the mean position of the start and end of the second block of 20 trials to be less than two steps apart. When this criterion was met, four 20-msec staircases were begun at different ISIs about the preliminary PSS. Once the four staircase starting positions were established, subjects were given 60 TOJNO trials. The experimenter terminated the stimuli approximately 500 msec after onset of the more delayed signal. Subjects indicated which signal they perceived as occurring first by depressing the appropriate microswitch after the stimulus ensemble was extinguished. No feedback was provided in this condition.

Once SRT, CMPRT, and TOJNO data had been collected, subjects were introduced to the two main experimental conditions (TOJAUD and TOJCUT) to determine the presence of a prior entry effect. Figure 7 (after Sternberg, et al., 1971) illustrates the paradigm employed. Depending upon which signal was primary and which auxiliary (auditory primary, cutaneous auxiliary in the TOJAUD condition; cutaneous primary, auditory auxiliary, in the TOJCUT condition), subjects were required to respond to the primary signal at its onset and immediately thereafter indicate which of the two signals had occurred first. To ensure selectivity of response, a random half of all trials were catch trials in which the auxiliary signal occurred alone after the variable foreperiod. The TOJAUD and TOJCUT conditions were, in reality, a

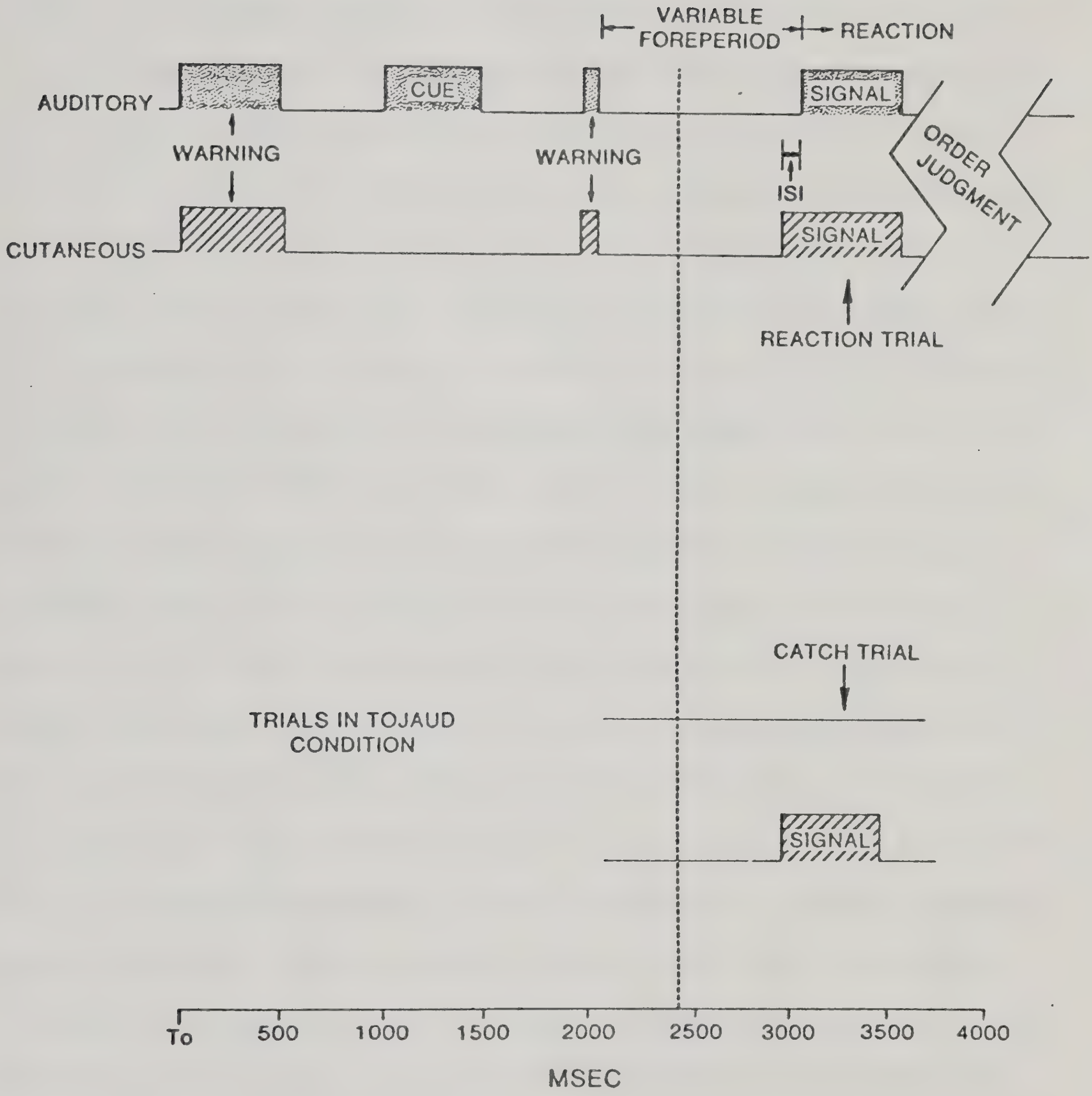

VARIABLE FOREPERIOD
REACTION
AUDITORY
CUE
SIGNAL
WARNING
WARNING
ISI
ORDER JUDGMENT
CUTANEOUS
SIGNAL
REACTION TRIAL
CATCH TRIAL
TRIALS IN TOJAUD CONDITION
SIGNAL
To
500
1000
1500
2000
2500
3000
3500
4000
MSEC

Figure 7. Concurrent TOJ and reaction time task employed in TOJAUD and TOJCUT conditions (after Sternberg, et al., 1971)

combination of the CMPRT and TOJNO paradigms in which the subject was required to make a selective response to bias attention to the primary signal and an order judgment of the relative occurrence of the two signal onsets. Twenty reaction trials were given per session and, to avoid fatigue, only one session per subject was administered per day. Four 20-msec staircases were interleaved at various ISIs on either side of the TOJNO PSS. Two of these staircases were positioned one-half step away from the other two staircases to provide ISIs 10 msec apart. This technique was introduced by Sternberg, et al. (1971) to increase precision and reduce any bias associated with larger ISI values. ISI values associated with a staircase were allowed to change only if the reaction time associated with the order judgment was within one standard deviation of the mean reaction time of the corresponding modality in the CMPRT condition for the first 20-trial block, and within one standard deviation of the mean of the previous TOJRT block for the remaining two TOJRT 20-trial blocks. Sternberg (1976) had indicated that in the original study (Sternberg, et al., 1971) reaction time performance "deadlines" had been established to maintain approximately 25% of the trials exceeding (being slower than) the deadline criterion. The current study's procedure of allowing a change in staircase position only if reaction time performance was within one standard deviation of the mean of the previous block of 20 reaction trials closely approximated the 25% "error" rate of the Sternberg, et al. (1971) study. Reaction time feedback using the "good-fast-very fast" technique described above was provided after the subject had indicated the TOJ. No TOJ feedback was given. Three sessions per condition were

completed which provided 60 separate trials at various ISIs 10 msec apart about the PSS for each of the TOJAUD and TOJCUT conditions. Mean TOJRT per modality and associated standard deviations were also tabulated per subject to compare reaction time performance between the CMPRT and TOJRT conditions. For reasons described above, however, no analyses between these two reaction time conditions were warranted.

In keeping with the methodology of Sternberg, et al. (1971), probit analyses (Finney, 1964) were undertaken to estimate the psychometric functions and points of subjective simultaneity for each of the attentional conditions. Appendix 4 describes the method of probit transformation, use of the probit regression line, and subsequent chi square analysis to determine goodness of fit of the regression of TOJ on ISI.

At the conclusion of all testing, subjects were debriefed as to the nature of the study and were asked to relate any strategies they employed in handling the concurrent reaction time-temporal order judgment task.

Analysis

All reaction time statistics and probit analyses of the TOJ data were computed on the Digital Equipment Corporation PDP 11/10 computer located in the Human Performance Laboratory in the Faculty of Physical Education, the University of Alberta. All plotting was output on a Typograph Model 3 terminal plotter under the control of the PDP 1130 computer at the Computer Center, San Diego State University, San Diego, California.

RESULTS

Mean cross modality matches of the cutaneous shock signal intensity to the invariant 72 db auditory white noise stimulus is provided in Table I. The session-to-session variability of the perceived intensity of the two signals averaged approximately 70 microamperes over all conditions. This amount of variance, caused by changes in skin conductance from session to session, indicated the importance of requiring a subjective match prior to every experimental condition rather than setting the cutaneous signal strength at the mean of previous intensities or at some arbitrary stimulus strength. In the Sternberg, et al. (1971) investigation, the cutaneous intensity was set at two times the threshold value determined prior to every session. The cross-modal method employed in this study appears to be a more accurate means of assessing subjective equivalence of signal strengths, especially in view of the fact that the threshold value of subjects seemed to remain relatively

Table I. Mean cross-modality matches of cutaneous shock signal to invariant 72 db band limited white noise (microamperes)

	Mean Current	Range
S1	120	105-140
S2	105	80-145
S3	135	90-195
S4	70	50- 95
S5	145	105-190
S6	110	70-160

constant despite the fact that there was approximately a 70-microampere average range from session to session.

Mean simple reaction time, standard deviation, and between 40 trial block t ratios are given in Table II. The critical value of t was set at +2.38 ($p < .01$) for a one tail test with 78 degrees of freedom. Negative t ratios indicate an upward trend in reaction time performance and hence a flattening or reversal of improved reaction time performance.

Without exception, all subjects reached an asymptotic CMPRT level by the second 20-trial block. As such, mean and standard deviation scores of the total 40 CMPRT scores are listed in Table III. Comparable TOJRT data is also tabulated in this table. Due to the methodology of including only those TOJ and reaction time data that met the one standard deviation deadline of the previous block of reaction time performance, all mean TOJRT scores, as expected, were faster than their corresponding CMPRT condition. This finding was important to the concurrent TOJ-reaction time task in that reaction times in the TOJRT condition were required to be equal to or faster than the corresponding CMPRT condition to satisfy the requirement of selective attention in the TOJAUD and TOJCUT conditions. Because TOJRT performance was, in all cases, better than CMPRT performance, it was reasonable to assume that there was an optimal selective attention bias to the primary signal in the TOJAUD and TOJCUT conditions.

Probit analyses provided psychometric functions for each subject per attentional condition. Table IV gives the PSS values and mean prior entry effect when PSS differences between TOJAUD and TOJCUT conditions

Table II. Mean simple reaction time, standard deviation and between block t ratios

		Auditory Blocks			Cutaneous Blocks			
Subject		1	2	3	1	2	3	4
1	$\bar{x}$	208	213		248	222	223	
	σ	15.65	24.9		35.0	25.0	23.8	
	t		-0.988			3.675*	0.002	
2	$\bar{x}$	275	212	230	256	257		
	σ	42.8	22.8	20.7	42.0	33.0		
	t		7.837*	-3.532		-0.100		
3	$\bar{x}$	264	208	210	260	235	206	216
	σ	31.3	19.3	38.2	29.4	63.2	25.1	39.0
	t		9.660*	-0.814		2.611*	2.596*	-1.508
4	$\bar{x}$	198	171	174	201	192		
	σ	49.6	20.1	21.6	33.2	33.4		
	t		3.088*	-0.512		1.089		
5	$\bar{x}$	199	207		211	218		
	σ	19.7	22.5		22.2	19.4		
	t		-1.789			-1.518		
6	$\bar{x}$	210	201		218	205		
	σ	36.8	41.8		28.7	26.2		
	t		0.961			2.130		

*1 tail test. 78 df, $p < .01$

Table I. Mean complex and temporal order judgment reaction time

		Auditory		Cutaneous	
Subject		CMPRT	TOJRT	CMPRT	TOJRT
1	$\bar{x}$	228	197	258	208
	σ	43.8	19.6	49.7	34.8
2	$\bar{x}$	205	198	257	215
	σ	23.2	34.3	51.6	44.7
3	$\bar{x}$	238	215	267	226
	σ	40.1	45.3	21.6	26.1
4	$\bar{x}$	198	174	205	154
	σ	42.0	28.3	40.9	22.6
5	$\bar{x}$	226	220	219	207
	σ	34.6	31.4	31.5	21.1
6	$\bar{x}$	229	203	248	207
	σ	31.4	27.7	37.0	39.6

were averaged over subjects. The average PSS value for the TOJNO (no experimentally induced attentional bias) condition (-18 msec) indicates that, for the subjects in this experiment, in order for the probability of perceiving one or the other of the two signals as occurring first to be .50, the onset of the cutaneous signal was required to precede the

Table II. Points of subjective simultaneity for attentional bias conditions and prior entry effects

Subject	TOJNO	TOJAUD	TOJCUT	Prior Entry Effect
1	+ 9	-30	0	30
2	-20	-14	+ 9	23
3	-46	- 7	-46	39*
4	-19	-62	+ 7	69
5	-14	-17	+24	41
6	-18	- 3	+ 8	11
$\bar{x}$	-18	-22	0	22

Mean prior entry effect: 22 msec

*Reversal effect

auditory signal by 18 msec. The PSS of -22 msec in the TOJAUD condition indicates that when the task required attention to be selectively biased to the auditory signal, there was a slight horizontal displacement (4 msec) of the curve indicating that the cutaneous signal could lead the onset of the auditory signal by 22 msec and the subject would nonetheless indicate that their onsets were subjectively simultaneous. In the TOJCUT condition, the effect of a horizontal displacement of the PSS due to attentional bias was readily evident. When subjects were required to react to, and therefore attend to, the onset of the cutaneous signal, the PSS shifted in the direction of positive ISIs

indicating that, in this condition, the PSS and POS (zero separation ISI) coincided. In other words, there was no longer a requirement for the cutaneous signal to lead by 22 msec in order for subjective simultaneity to occur; there had been a 22-msec shift in the PSS. With the exception of Subject 3, who evidenced a 39-msec reversal effect, all subjects showed a prior entry effect that ranged from 11 to 69 msec. Excluding Subject 3's data, the mean prior entry effect was 35 msec which closely approaches the 50-msec effect as reported by Stone (1926), but is only half as great an effect as that reported by Sternberg, et al. (1971). In view of the fact that the mean prior entry effect in the Sternberg, et al. study was based only upon three "experienced" subjects of the total six subjects employed, however, it may be argued that the results of this study more closely approximate the average effect over all subjects naive to the prior entry law. As suggested by Frey & Wilberg (1975), the cause of the prior entry effect may be due to an a priori knowledge of the law. In the Sternberg, et al. (1971) study, the three "experienced" subjects were the experimenters themselves. In view of this, the fact that the prior entry effect was not as large as previously reported, does not seem to be a cause of alarm. Even the fact that one of the six subjects showed a reversal effect is quite interesting in that Sternberg, et al. (1971) also reported that one of their subjects evidenced an uncharacteristic reversal effect.

The individual and mean prior entry effects are represented in Figure 8. The 95% confidence interval bracketing the mean prior entry effect is based upon between-subject differences. Ogives fitted to the individual

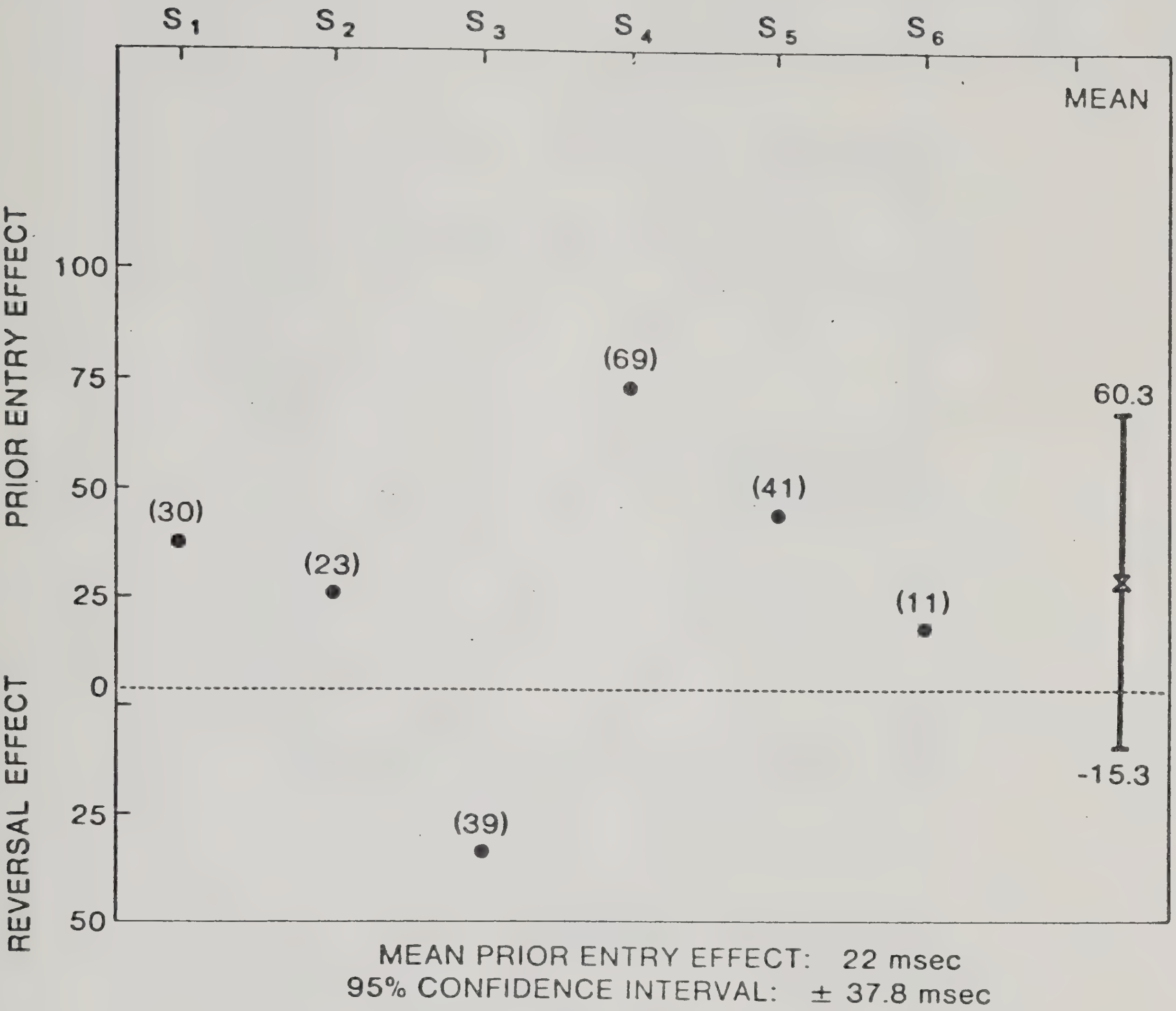
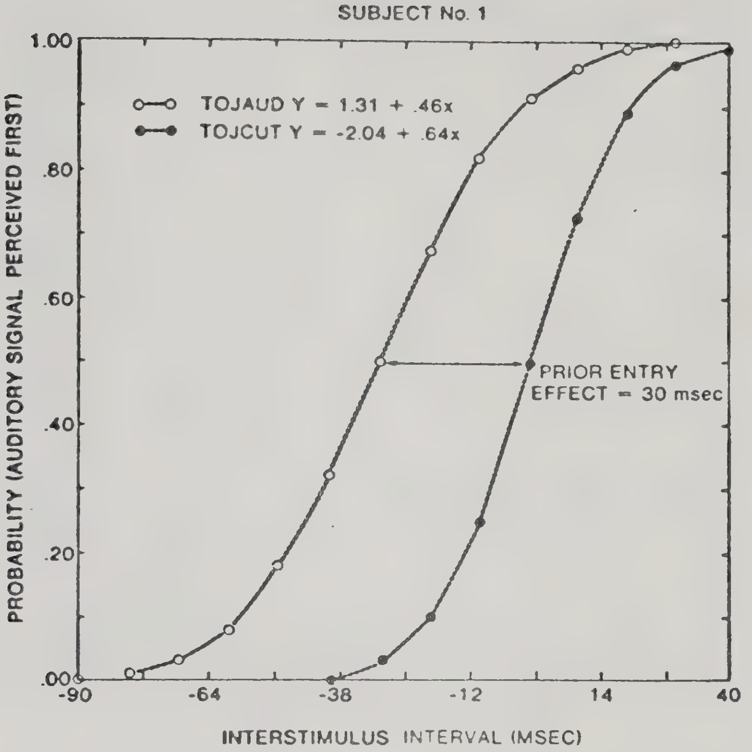


Figure 8. Individual and mean prior entry effects (msec)

psychometric functions for all subjects for the TOJAUD and TOJCUT conditions are provided in Figures 9 through 11. All functions show fitted proportion of trials in which the auditory signal was reported as being perceived first. All raw proportions are provided in Appendix 5.

The statistical significance of the horizontal displacement of the PSS points was considered by means of a two treatment, repeated measure design with subjects considered random and treatments fixed (see Appendix 1). PSS data per attentional condition served as the appropriate dependent variable. The analysis of variance with alpha


SUBJECT No. 1

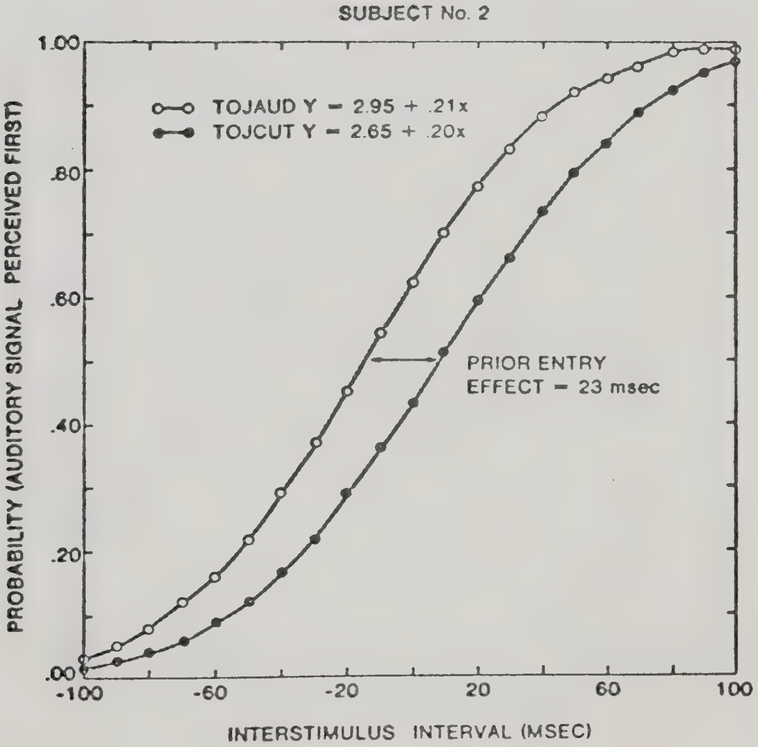

SUBJECT No. 2

Figure 9. Psychometric functions for TOJAUD and TOJCUT conditions (Subjects 1 and 2)

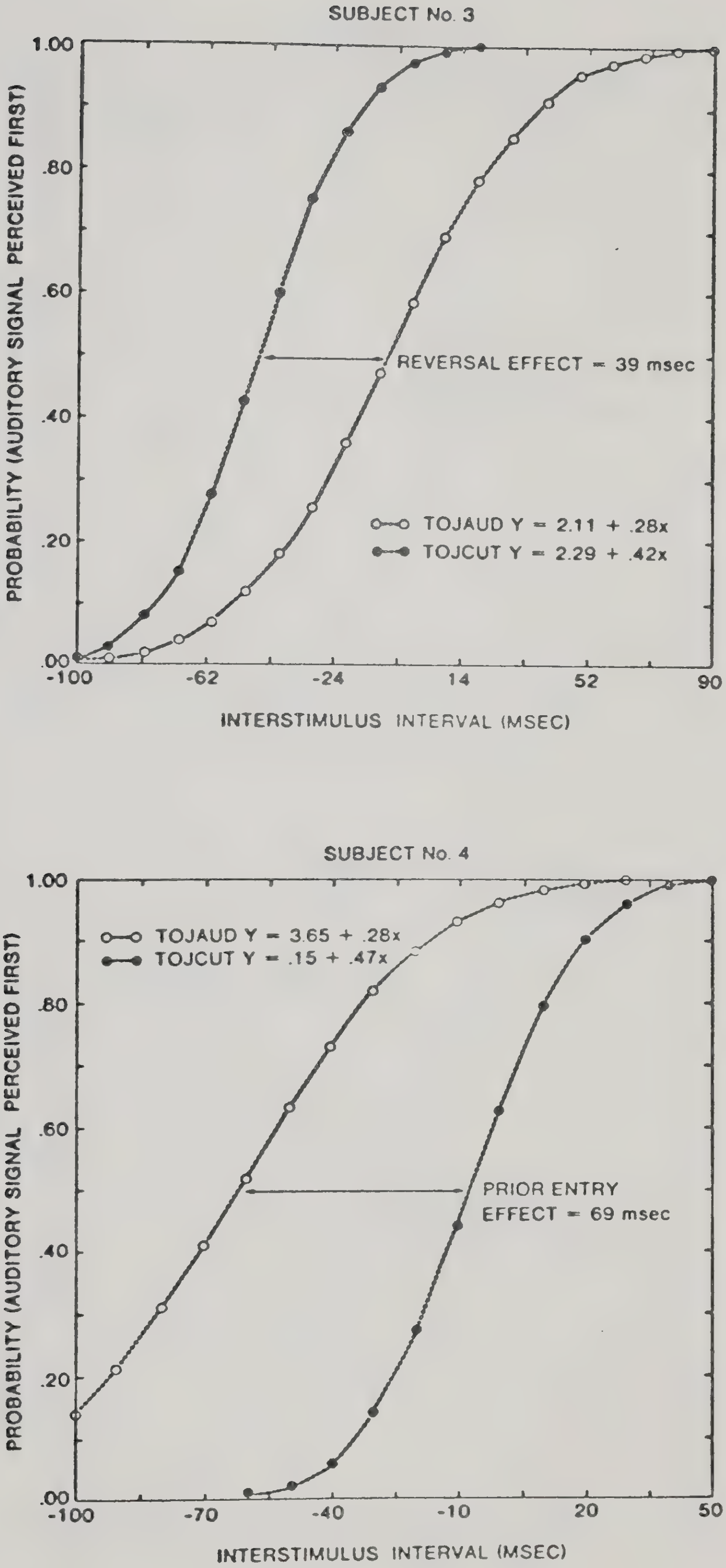
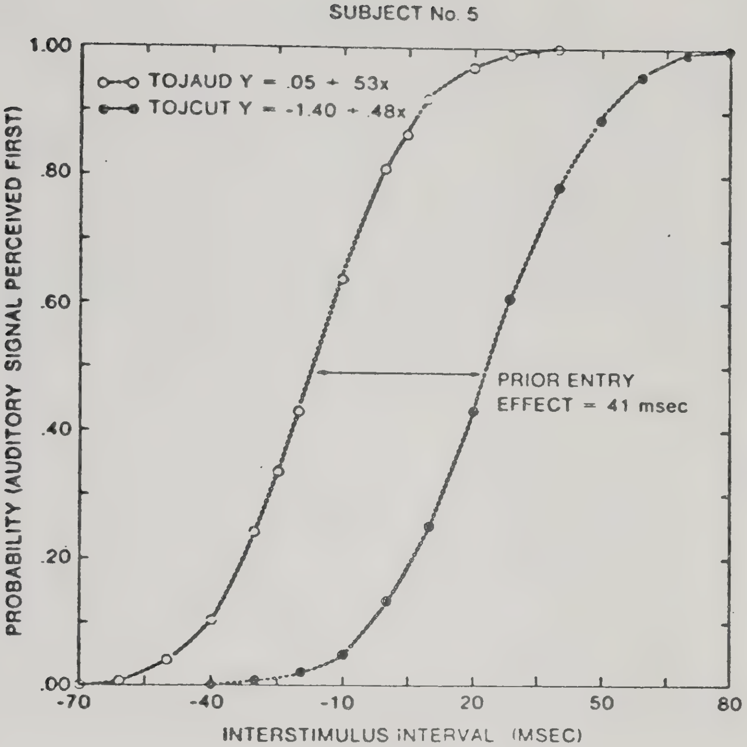


Figure 10. Psychometric functions for TOJAUD and TOJCUT conditions (Subjects 3 and 4)



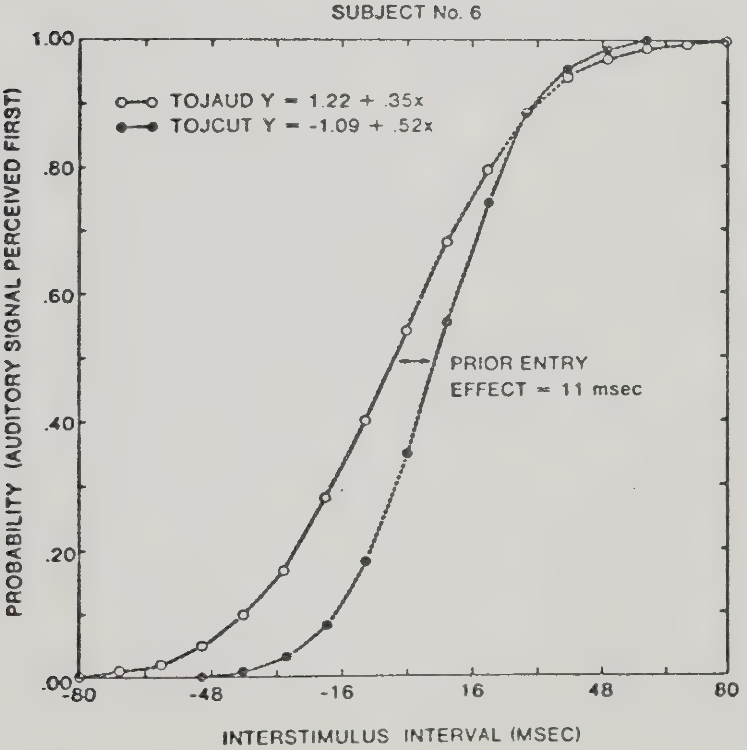


Figure 11. Psychometric functions for TOJAUD and TOJCUT conditions (Subjects 5 and 6)

set at the .05 level evidenced an insignificant treatment effect ($F_{(1,4)} = 2.34$, $p > .10$) indicating that, despite a prior entry effect of 22 msec in the expected direction, statistically the prior entry hypothesis was not supported. In view of the above, the data generated by this experiment failed to reject the initial hypothesis that temporal order perception would not be affected by the locus of attention.

Experiment II

METHODOLOGY

Purpose

A complete replication of the Sternberg, et al. (1971) methodology provided results that did not statistically support the prior entry hypothesis. The results of Experiment I did, however, reveal a definite prior entry trend for five of the six subjects. Because Sternberg, et al. (1971) did not analyze PSS data for a significant attentional treatment effect, it cannot be known if, even in that investigation, there would have been a statistically significant prior entry effect. This is indeed unfortunate in that, to date, the Sternberg, et al. (1971) study has provided the strongest evidence in favor of the prior entry doctrine.

Experiment II was concerned with an investigation of the one variable that remained a confounding factor in the discrepancy between the statistically negative prior entry evidence of Frey & Wilberg (1975) and Experiment I, on the one hand, and the empirically positive prior entry trend results of Sternberg, et al. (1971) and Experiment I on the other. Auditory-visual pairs had been used in the Frey & Wilberg study following the methodology used by Sternberg, et al. in their second experiment. A prior entry effect, although only about 30 msec when averaged over subjects, was reported in that experiment. Due to the fact that no prior entry effect was evidenced in the Frey & Wilberg investigation employing auditory-visual pairs, it was considered a possibility that the auditory-cutaneous complication was required for an optimal effect to occur. In light of the fact that, despite its

statistical insignificance, there was a 22-msec PSS displacement in Experiment I, yet in the Frey & Wilberg (1975) investigation the psychometric functions completely overlapped (see Figure 2), this point of view was sustained. The question was raised: If auditory-visual pairs, naive subjects, and the Sternberg, et al. (1971) methodology were employed would the prior entry effect occur?

Sternberg (1976) has suggested that the reason that he and coworkers did not evidence as large a prior entry effect with auditory-visual pairs as with auditory-cutaneous pairs may be due to the fact that the cutaneous and auditory systems are more "similar" than the visual and auditory systems and hence more attentional bias (suppression or selection) was required to avoid false positive reactions. This point of view parallels that discussed earlier when reviewing gnostic unit activation (Konorski, 1967) and the cognitive masking that may take place in gnostic fields (Walley & Weiden, 1974). It was considered a possibility that the prior entry effect might be a function of the "similarity" of the physiological mechanisms subserving the different sense modalities. One earlier finding by Needham (1934), however, suggested that such an hypothesis may be invalid. Needham tested the prior entry phenomenon using homogeneous stimulus pairs and obtained only a modest prior entry effect. Unfortunately, Needham's methodology is open to question due to the fact that, similar to Stone (1926), he neglected to control unequivocably for attentional shifts. The fact that Sternberg, et al. (1971) did obtain a prior entry effect when using an auditory-visual complication should be explained. It might be possible that the *a priori* knowledge of three of the subjects in that

study was adequate to cause an artifact of prior entry to occur. Due to the fact that all subjects in the Frey & Wilberg (1975) study were naive to the prior entry doctrine, there was no a priori interaction with the sensory modalities and perhaps therein lies the reason why not the slightest evidence of a prior entry effect surfaced. This hypothesis gains strength when it is realized that the mean prior entry effect with auditory-visual pairs was less than half of the effect when auditory-cutaneous signals were employed in the two Sternberg, et al. (1971) investigations. The fact that experimental methodologies were also different between the two studies further confounds the question of sense modality, naivete, and prior entry.

Experiment II was designed to unconfound the remaining discrepancies between the Sternberg, et al. (1971) and the Frey & Wilberg (1975) studies by using naive subjects, the Sternberg, et al. methodology, and auditory-visual stimulus pairs.

Dependent Variables

To ensure that an attentional bias was maintained in the TOJAUD and TOJVIS conditions, reaction time performance in the TOJRT condition was required to be equal to or faster than the corresponding CMPRT condition. Similar to Experiment I, TOJ ability was the main dependent variable of experimental interest.

Preliminary Procedures

As in Experiment I simple reaction time data were collected to determine individual reaction time differences between the two sensory

modalities and to provide the subjects an opportunity to gain familiarity with the reaction time apparatus.

Cross modality matches for intensity were conducted before the first three experimental sessions. The procedure required the subject to adjust the auditory white noise signal until its intensity matched the invariant illuminance of a 125 v, 1/3 watt, experimental snaplight, one centimeter in diameter. Because of the very small decibel variance in the first three sessions, the mean db intensity of the auditory stimulus was used for all remaining sessions.

Experimental Design

The experimental design was identical to that employed in Experiment I.

Task

The task was similar to that in Experiment I except that the stimulus pairs were in the auditory and visual sensory modalities.

Apparatus

The apparatus was identical to that used in Experiment I except that the cutaneous shock electrodes were replaced by a 15 cm by 25 cm plywood rectangle situated in the vertical plane, in the middle of which was a Leecraft model 3200 Experimental Snaplight. The neon lamp was located approximately 75 cm away from the seated subject at eye level. Low voltage was passed through the visual circuit, causing an attenuated glow behind the lens of the light making it easy to fixate

in the dimly lit experimental room. At stimulus onset, the post-energized condition was sufficiently strong to preclude any false alarms of stimulus onset during the pre-energized condition. The "Arm"-labeled microswitch used in Experiment I to indicate TOJs was relabeled "Eye."

Subjects

Because of fairly large individual differences associated with the PSS data of the subjects in Experiment I, it was desirable to see if subjects who had evidenced a prior entry effect would do so again under the different stimulus conditions. In this regard, three of the subjects from Experiment I who had generated prior entry effects (Subjects 2, 4 and 5) volunteered to be tested in Experiment II. The remaining three subjects were also unpaid volunteer graduate students in physical education at the University of Alberta. Similar to Experiment I, all subjects were right handed and had no *a priori* knowledge of the law of prior entry.

Procedure and Data Analysis

All experimental procedure and analysis of the data were identical to that employed in Experiment I.

RESULTS

Cross modality matches for intensity between the visual and auditory signals are given in Table V. The session-to-session variability of the perceived intensity of the two signals was negligible.

Table V. Mean cross modality matches of auditory white noise signal to invariant white light stimulus (db)

	Mean Intensity
S1	70
S2	68
S3	72
S4	73
S5	71
S6	70

Mean simple reaction time, standard deviations, and between block t ratios are provided in Table VI. Similar to Experiment I, negative values of t and positive values less than 2.38 indicated an insignificant improvement in the mean reaction time between blocks of trials.

All subjects provided CMPRT data which yielded insignificant t ratios for between block means. The mean CMPRT and TOJRT values and associated standard deviations are given in Table VII. Subjects 2, 4 and 5 in Experiment I retained the same designations in Experiment II. With the exception of Subject 4, who showed a 32-msec improvement in CMPRT performance, the auditory aspect of their CMPRT and TOJRT mean values is fairly similar. Subject 2 was the only subject to evidence a higher TOJRT mean than CMPRT mean in either modality. This subject's TOJRT mean of 217 in the auditory mode was 17 msec over the corresponding

Table VI. Mean simple reaction time, standard deviation and between block t ratios

		Auditory					Visual		
		Blocks					Blocks		
Subject		1		2		3	1		2
1	$\bar{x}$	206		184		216	245		242
	σ	39.1		19.4		27.2	17.4		17.8
	t		2.74		-5.74			0.54	
2	$\bar{x}$	275		212		230	226		216
	σ	42.8		22.8		20.7	36.4		27.1
	t		7.837*		-3.532			1.46	
3	$\bar{x}$	202		193			228		224
	σ	17.0		16.8			20.9		31.5
	t		2.24					0.61	
4	$\bar{x}$	198		171		174	183		180
	σ	49.6		20.1		21.6	28.5		20.9
	t		3.088*		-0.51			0.10	
5	$\bar{x}$	199		207			234		234
	σ	19.7		22.5			16.2		16.2
	t		-1.79					0.00	
6	$\bar{x}$	176		172			210		211
	σ	16.6		19.6			23.6		17.6
	t		0.84					-0.44	

*1 tail test, 78 df, $p < .01$

Table VII. Mean complex and temporal order judgment reaction time (msec)

Subject		Auditory		Visual	
		CMPRT	TOJRT	CMPRT	TOJRT
1	$\bar{x}$	220	206	235	217
	σ	37.9	33.1	21.5	27.7
2	$\bar{x}$	200	217	225	214
	σ	33.2	25.4	19.9	21.9
3	$\bar{x}$	207	190	249	210
	σ	31.77	21.8	26.89	24.4
4	$\bar{x}$	166	165	192	178
	σ	26.5	36.3	24.7	33.2
5	$\bar{x}$	228	209	261	226
	σ	32.2	46.6	43.2	15.7
6	$\bar{x}$	186	183	220	206
	σ	28.6	26.0	23.0	16.1

CMPRT mean. Even under an optimal attentional bias, this result is not completely improbable in that the standard deviation of the CMPRT mode was sufficiently high to allow for some deviance over the mean CMPRT mean. In this case, the standard deviation of the corresponding CMPRT condition was 33.2 and half of this value was the allowable "deadline" over the CMPRT mean. Seventeen msec was less than a millisecond over

this cutoff point and was considered within reasonable limits of an optimal attentional bias. Because TOJRT performance was faster than, or at least equal to, CMPRT performance, it was concluded that, for all subjects, attention was optimally biased to the primary signal in the TOJAUD and TOJVIS experimental conditions.

As in Experiment I, probit transformation, regression lines, and psychometric functions were computed for each attentional condition. Table VIII lists the PSS for each subject for the TOJNO, TOJAUD, and TOJVIS conditions, as well as individual prior entry effects. The mean TOJNO value of -33 indicates that, when not under any experimentally induced attentional bias, subjects required the visual signal to precede the auditory stimulus by 33 msec in order for subjective simultaneity to occur. As in Experiment I, there was a horizontal shift in opposite directions from the TOJNO PSS for the points of subjective simultaneity for the two experimentally induced attentional conditions. In the TOJAUD condition, the mean PSS was -66 indicating that, when subjects were attending to the auditory signal, the visual stimulus could precede the noise signal by 66 msec and subjects, on the average, would report simultaneity. Conversely, when the visual stimulus was the primary signal, the light signal only needed a 27-msec lead time over the auxiliary auditory stimulus for subjects to report simultaneity. The mean displacement of the psychometric functions was 39 msec, a value nearly twice as large as the prior entry effect evidenced in Experiment I. Similar to the results of Experiment I, a reversal effect surfaced. The effect was evidenced by both Subjects 2 and 6. It was not considered unusual that one of the subjects might provide data contrary to

Table VIII. Points of subjective simultaneity for the TOJNO, TOJAUD, and TOJVIS conditions and individual prior entry effects

Subject	TOJNO	TOJAUD	TOJVIS	Prior Entry Effect
1	-38	-75	-28	47
2	+14	-13	-37	24*
3	-31	-75	-26	49
4	- 3	-85	34	119
5	-73	-99	-48	51
6	-69	-50	-59	9*
x̄	-33	-66	-27	39

Mean prior entry effect: 39 msec

*Reversal effect

the prior entry hypothesis, in view of the fact that the reversal effect came to light in Experiment I and in Sternberg, et al. (1971). What was unexpected was the fact that Subject 2, who had shown a prior entry effect in Experiment I, also demonstrated a reversal effect. Although this subject did not report any unusual strategy in handling the task in either Experiment I or II, it is interesting to note that the magnitude of the two effects is almost identical (23 and 24 msec, respectively). This suggests that this subject may have subconsciously reversed the visual-auditory and visual-cutaneous tasks while maintaining temporal order precision. Table IX compares the points of subjective

Table IX. Comparison of points of subjective simultaneity and prior entry effects between Experiment I and Experiment II for inter-experimental subjects

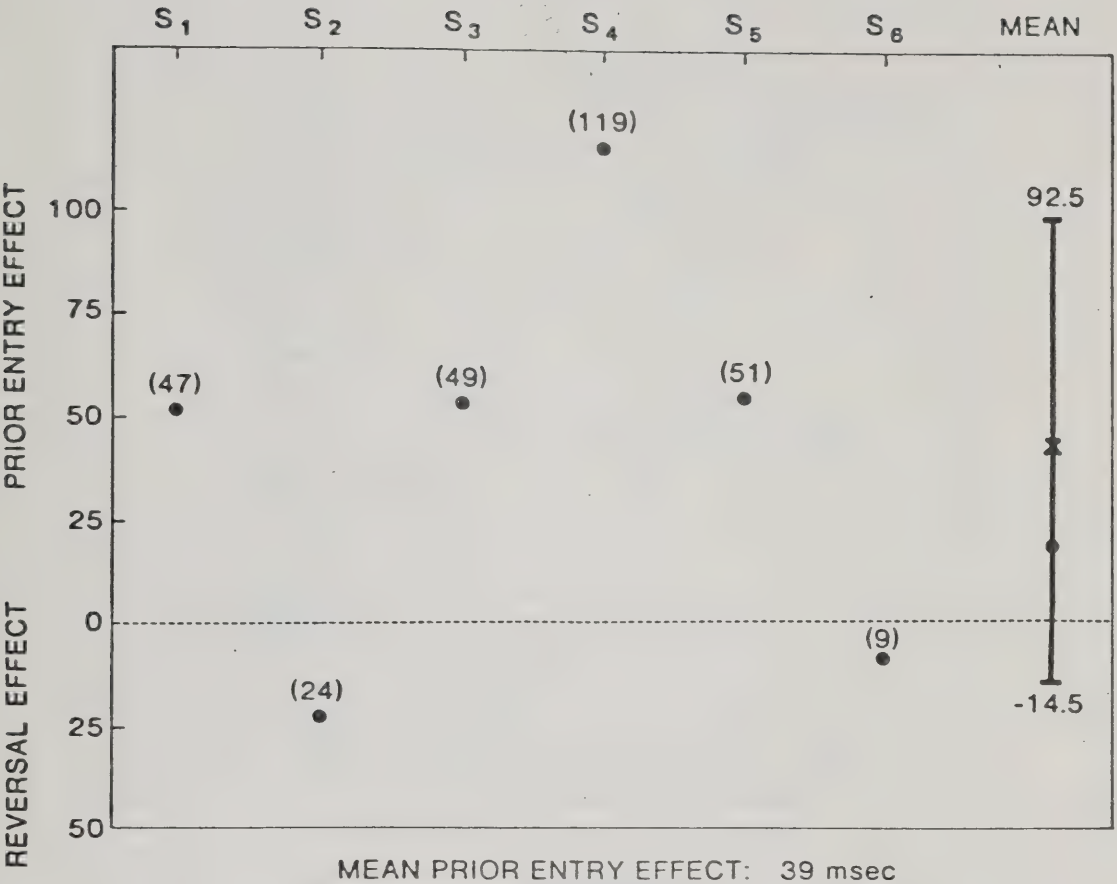
Subject	TOJNO		TOJAUD		TOJCUT TOJVIS		Prior Entry Effect	
	Experiment		Experiment		Experiment		Experiment	
	I	II	I	II	I	II	I	II
2	-20	14	-14	-13	9	-37	23	24*
4	-19	- 3	-62	-85	7	34	69	119
5	-14	-73	-17	-99	24	-48	41	51
$\bar{x}$	-18	-21	-31	-66	13	-17	44	49

Experiment I mean prior entry effect: 44 msec

Experiment II mean prior entry effect: 49 msec

*Reversal effect

simultaneity and prior entry effects of the three inter-experiment subjects. From this table it appears that the source of Subject 2's reversal effect is located in the TOJAUD condition in that this subject's PSS did not demonstrate the more negative ISI trend characterized by the other two subjects. It is interesting to note that, despite the reversal effect demonstrated by Subject 2 and the 50-msec increase in the prior entry effect of Subject 4, the mean prior entry effect of the three inter-experiment subjects remained relatively unchanged (44 msec and 49 msec, respectively). Figure 12 represents the individual and mean prior entry effects for all subjects in Experiment II. The 95% confidence interval bracketing the mean effect is

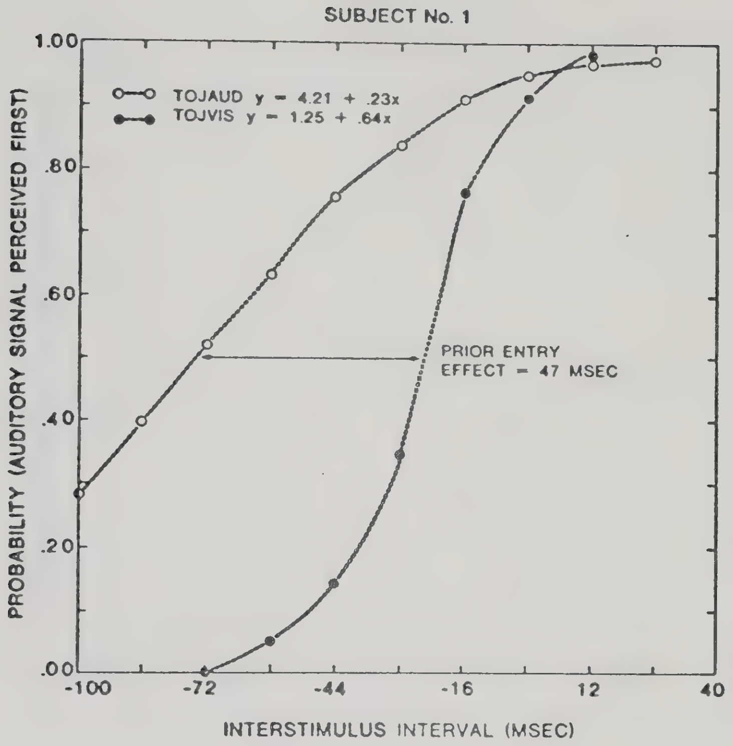


MEAN PRIOR ENTRY EFFECT: 39 msec
95% CONFIDENCE INTERVAL: ± 53.5 msec

Figure 12. Individual and mean prior entry effects (msec)

based upon between-subject differences. As in Experiment I, the relationship between ISI and the probability that the auditory signal was perceived first has been individually represented in Figures 13 through 15. Appendix 5 provides all raw proportions by ISI per subject.

Due to the fact that the mean prior entry effect was nearly twice as large as that obtained in Experiment I, it was expected that the effect would attain statistical significance. This was not to be the case. The critical value of F with one and four degrees of freedom at the .05 level of confidence was 7.71; however, the ANOVA for the attentional effect on TOJ ability for this experiment revealed an



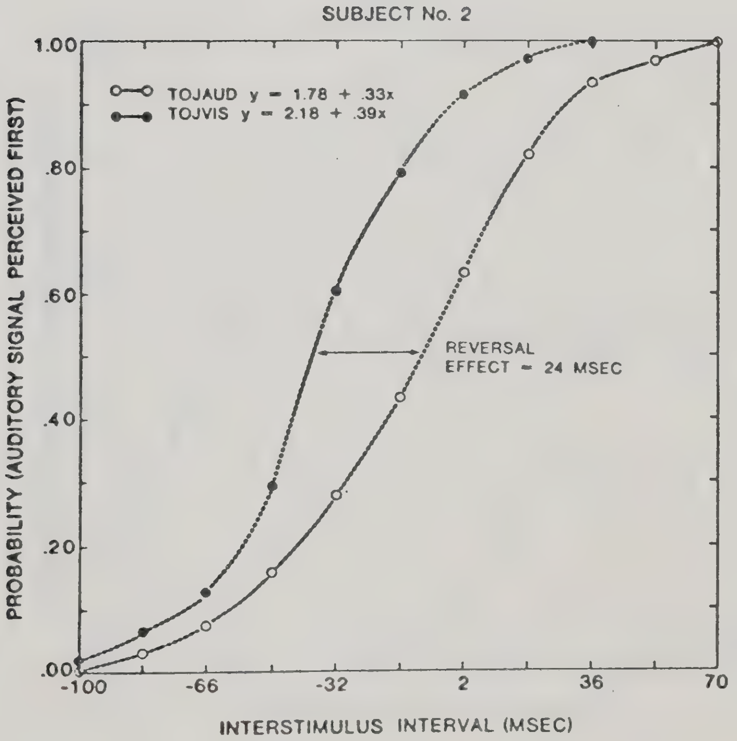


Figure 13. Psychometric functions for TOJAUD and TOJVIS conditions (Subjects 1 and 2)

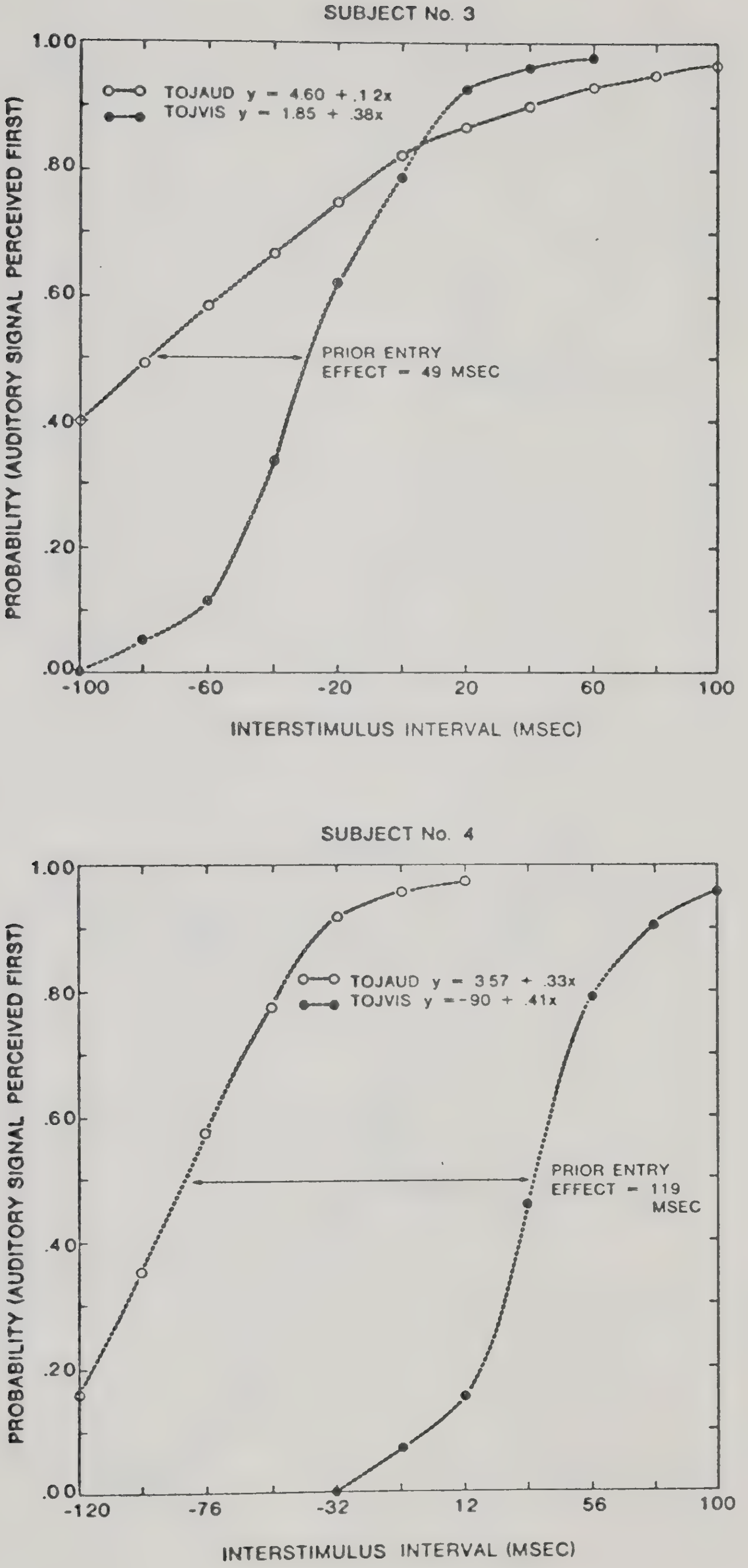
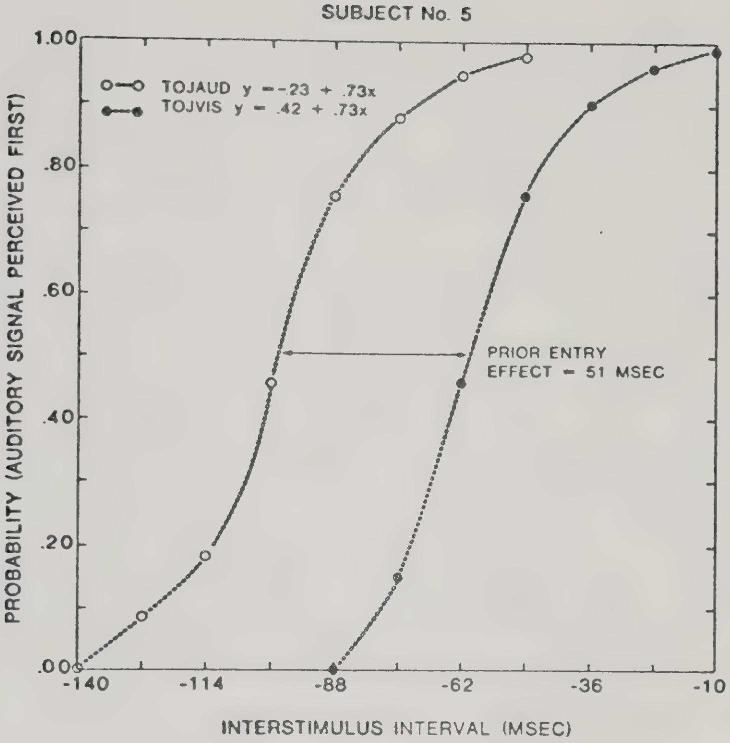


Figure 14. Psychometric functions for TOJAUD and TOJVIS conditions (Subjects 3 and 4)



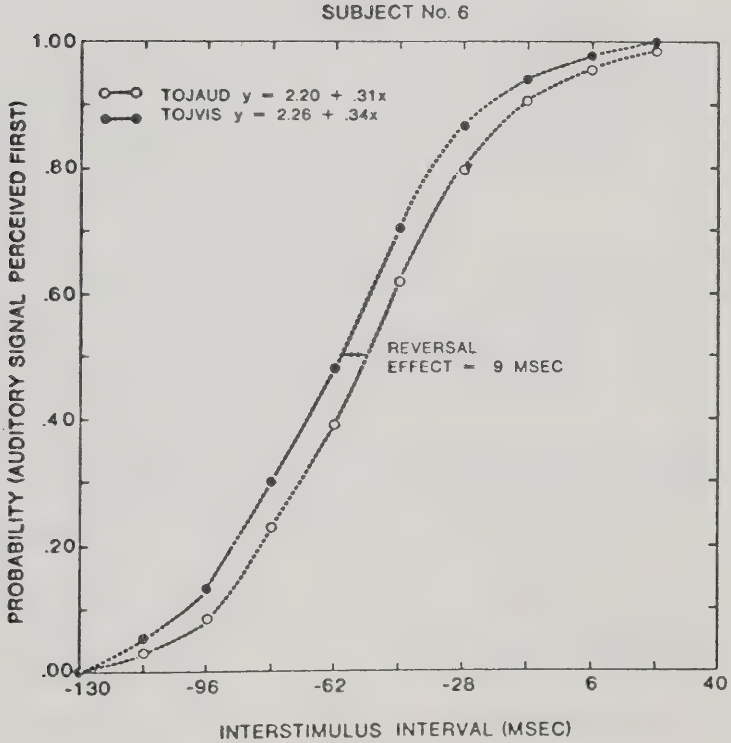


Figure 15. Psychometric functions for TOJAUD and TOJVIS conditions (Subjects 5 and 6)

insignificant treatment effect ($F_{(1,4)} = 3.50$, $p > .10$). In addition to the insignificant effect found in Experiment I, the results of this experiment provided further evidence against the validity of the prior entry doctrine. Yet, analogous to Experiment I, there was a definite tendency for the psychometric functions to be displaced depending upon the attentional focus of the subject. The mean PSS shift of 39 msec was in close agreement with the 30-msec prior entry effect reported by Sternberg, et al. (1971) for the auditory-visual complication, and was not that far removed from the 55-msec effect reported by these experimenters for auditory-cutaneous pairs when averaged over both experienced and naive subjects. In view of the fact that naive subjects judging auditory-visual pairs evidenced nearly a 40-msec horizontal displacement of the relevant attentionally biased functions, there was a strong indication that it was experimental methodology and neither the a priori knowledge of subjects nor the specifics of an auditory-cutaneous complication that were responsible for the different results in the Frey & Wilberg (1975) and the Sternberg, et al. (1971) investigations. These results underscore the importance of exact replication of methodology when attempting to export perceptual phenomena between laboratories.

Unlike the non-parametric signal detection methodology employed in Cairney (1975a), the advantage of the Sternberg, et al. (1971) procedure of plotting the psychometric shift of the TOJ functions enabled a determination to be made as to the actual PSS displacement for each experimental condition. The results of a negative prior entry effect reported in Cairney (1975a) offered no indication of the trend or bias

of response that might be predicted were the experimental procedure of that study replicated. More regrettably, the study did not indicate observed PSS data for subjects in the different conditions examined. As such, no determination may be made as to the relative approach of the data toward statistical significance in that investigation. This shortcoming of the experimental procedure in Cairney (1975a) is indeed unfortunate due to the fact that the study claims to have offered the most damaging evidence against the doctrine of prior entry. It was considered a possibility that despite a statistically unequivocal denial of the prior entry effect in the Cairney (1975a) study there may have been an empirical PSS displacement in that study similar to that observed in Experiments I and II of this investigation. The fact that the original hypothesis of this study, namely, that attentional focus should not effect TOJ ability, has been supported did not, in and of itself, serve as the basis for a complete rejection of Titchener's (1908) law. Psychometric functions were displaced and a mean prior entry effect for both experiments was slightly greater than 30 msec. Experiment III addressed itself to the question of why there should be PSS shifts at all; and, regardless of the significance or insignificance of the magnitude of these function displacements, why they should be, on the average, in the direction predicted by the prior entry doctrine.

Experiment III

METHODOLOGY

Purpose

The results of Experiments I and II failed to give statistically significant support to the viability of the prior entry doctrine. Based upon the computed F ratios for attentional treatment effects on TOJ ability, the magnitude of the observed effects failed to reach significance. The fact remained, however, that, when all subjects who evidenced prior entry data were separately pooled, the mean prior entry effect of the two experiments averaged 49 msec. This degree of differentiation in the perceptual processing of closely-successive signals was considered psychologically significant in that in high speed perceptual motor tasks involving decisions concerning the relative occurrence of heteromodal stimuli, any stimulus-specific differentiation in perceptual processing appears to cause decisional task performance to be characteristically biased in the direction of the differentially-treated stimulus. Even a differential perceptual shift as small as 30 msec, the mean prior entry effect for all subjects in Experiments I and II, is, therefore, of experimental interest. In this regard, the main spirit of Experiment III was an attempt to determine why there should have been any psychometric displacement in the two experiments reported by Sternberg, et al. (1971) and in Experiments I and II of the present study, and especially why the horizontal shifts of the points of subjective simultaneity should have occurred in the direction predicted by the doctrine of prior entry.

LaBerge (1973) has shown that perceptual processing of two signals may occur simultaneously if such processing is part of the task demands. However, as Treisman (1960) has suggested, the unattended signal in a dual stimulus presentation is often attenuated to ensure focused attention. Norman (1968) would say that in such a task the "attended" signal has a higher pertinence weighting and hence enjoys the benefit of more favorable processing. By using the concurrent reaction time-temporal order judgment paradigm developed by Sternberg, et al. (1971), it has been demonstrated that the perception of the order of stimulus events may be manipulated. The prior entry explanation for the demonstrated PSS displacement is that the speed of the detection process in the attended channel is enhanced; the unattended signal failing to enjoy such enhancement. This point of view suggests that there may be an afferent neural inhibition of the unattended signal as suggested by Hernandez-Peon and co-workers (1956) or a type of filtering process that allows for the immediate processing of relevant input (Broadbent, 1958). Both the Hernandez-Peon, et al. hypothesis and Broadbent's filter theory, however, have fallen into disrepute; the former because of a failure of replication and the latter due to its inability to explain certain data (Gray & Wedderburn, 1960; Treisman, 1960). Further evidence against the hypothesis that the role of selective attention is specific to pre-detection mechanisms has been provided by Sternberg, et al. (1971). These investigators found that, despite manipulating stimulus intensities, there was no observable effect on the prior entry phenomenon. If perceptual processes in the channels themselves were responsible for the effect, it would be expected that by increasing stimulus intensities the prior entry effect would be

reduced (see the Grice-John Criterion Model in Sternberg, et al. (1971)). These results suggest that the locus of the prior entry effect is not organic to the channel itself but alternatively the role of attention appears to have an effect on a more central decision center. One way that this might occur is if processing subsequent to detection were more appropriated to the attended signal. It may be possible that detecting the appropriate signal for a speeded response requires more of the limited capacity processor (Moray, 1967; Kahneman, 1973) than rejecting the occurrence of any unattended signal. When consideration is given to the fact that, after the final warning signal, the subject is rather routinely rejecting irrelevant stimuli, both in a not totally controlled surround as well as within his own internal noise distribution (Green & Swets, 1966), this possibility gains strength. As such, the subjective awareness of temporal order may be affected by the fact that the processing subsequent to signal detection is not equal for the attended and unattended channels. In this regard, the channel requiring more processing capacity is "highlighted" in perception and is perceived as occurring first. Figure 16 illustrates this unequal processing model and how an unbalanced processing task may affect the TOJ decision. This model does not complement the prior entry doctrine. It suggests that the detection of signals occurs in parallel constrained, of course, by channel-specific neural latencies. The fact that an attended signal is more often perceived as occurring first is due to unequal processing in the attended channel which has an effect on the decision mechanism. The actual arrival times of the two signals are in correspondence with the objective state of their onsets. The

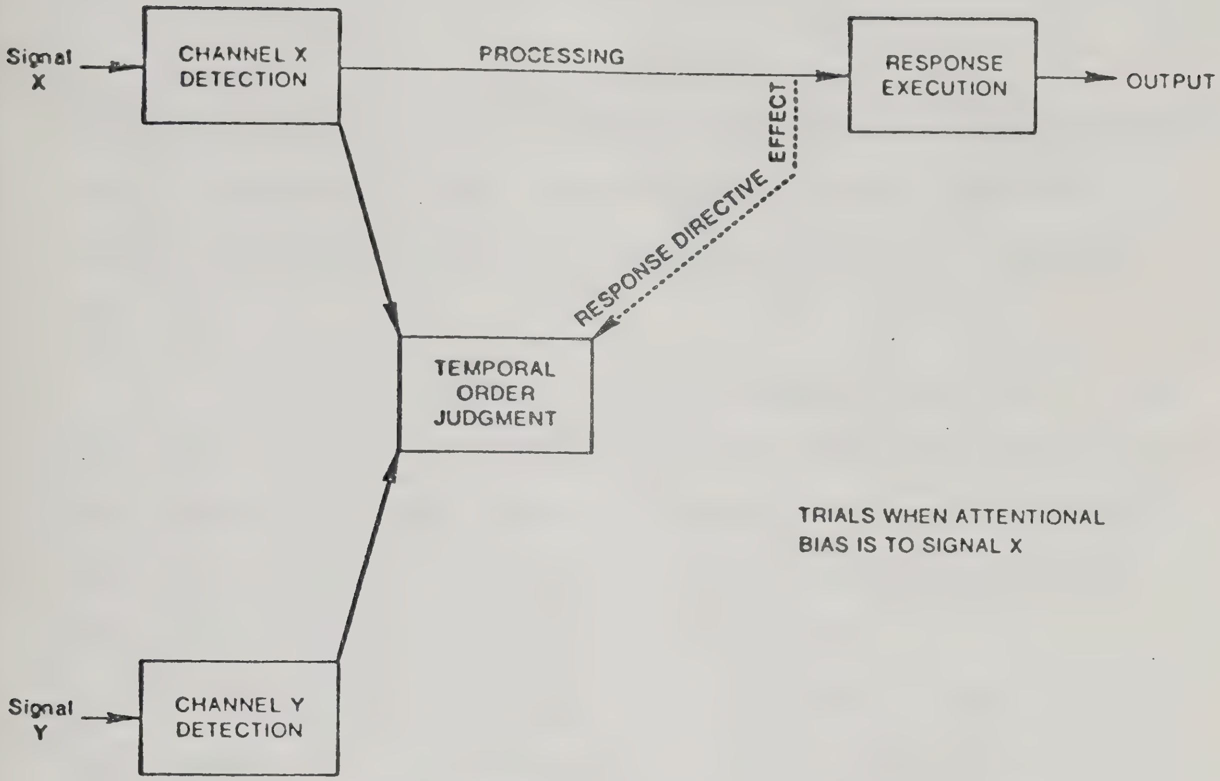

Signal X
CHANNEL X DETECTION
PROCESSING
RESPONSE EXECUTION
OUTPUT
EFFECT
RESPONSE DIRECTIVE
TEMPORAL ORDER JUDGMENT
TRIALS WHEN ATTENTIONAL BIAS IS TO SIGNAL X
Signal Y
CHANNEL Y DETECTION

Figure 16. The effect of unequal channel processing and temporal order judgment performance

assumed mediator in the phenomenon is the relative amount of processing subsequent to detection appropriated to the two signals.

The model illustrated in Figure 16 indicates a greater information load in Channel X. The onset of stimulus X not only carries its order information but also the response initiation information associated with the concurrent reaction time task. In this example, then, the fact that a greater pertinence weighting (Norman, 1968) in Channel X requires central processing while subsequent to detection no processing occurs in Channel Y, is the theoretical explanation for the characteristic prior entry effect.

To test such an hypothesis it was necessary to design a task that would require more equal post-detection information processing in the two channels. In this way the simple detection of the occurrence of sensory information in the two channels would no longer be adequate

to optimize the task demands; therefore, the response-initiation information in the attended channel would be relatively more equalized, and theoretically any prior entry trend would be reduced or completely diminished.

The experimental task designed to test the unequal processing hypothesis was similar to the auditory-visual concurrent reaction time and temporal order judgment paradigm employed in Experiments I and II. The only difference in the task employed in Experiment III was the increased information load carried by both signals.

Immediately after responding to the primary signal, subjects were required not only to indicate the order of the signals but also were required to identify the nature of one of the stimuli (ie, high or low frequency tone in the auditory channel or amber or red light in the visual channel). In this task, then, the subject was required to process both signals equally because of uncertainty from trial to trial as to which stimulus information would be required. It was predicted that if processing subsequent to detection was responsible for the prior entry trend observed in previous studies, by requiring subjects to more equally process the attended and unattended signals, the effect would either be attenuated or completely disappear. Figure 17 illustrates the theoretical effect of a more equalized channel processing task on TOJ performance. In this model the effect of parallel processing of both attended and unattended signals is shown to equally affect the TOJ center. Any bias associated with unequal processing in the channels is theoretically minimized.

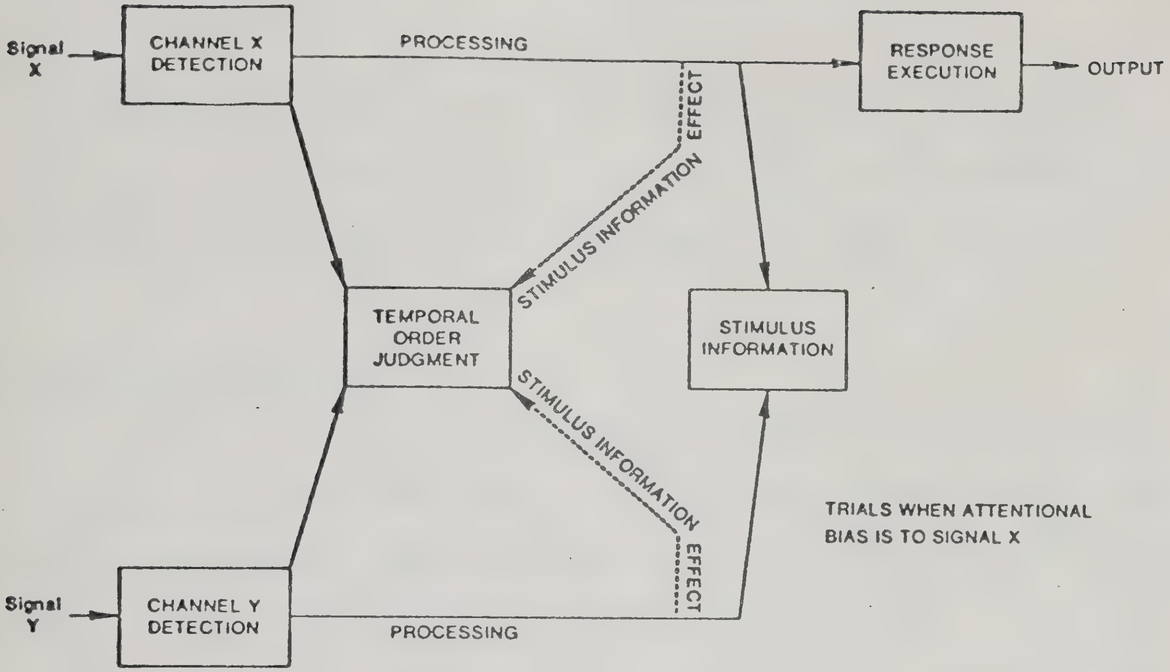

Signal X
CHANNEL X DETECTION
PROCESSING
RESPONSE EXECUTION
OUTPUT
EFFECT
STIMULUS INFORMATION
TEMPORAL ORDER JUDGMENT
STIMULUS INFORMATION
STIMULUS INFORMATION
EFFECT
TRIALS WHEN ATTENTIONAL BIAS IS TO SIGNAL X
Signal Y
CHANNEL Y DETECTION
PROCESSING

Figure 17. The effect of relatively equal channel processing and temporal order judgment performance

Experiment III was designed to test the hypothesis that the prior entry effect evidenced in previous studies was a function of an unequal informational load associated with the attended and unattended channels. The operational hypothesis to be tested in this experiment was that as long as processing subsequent to signal detection remained relatively equal in both the attended and unattended channels, there would be little or no prior entry effect evidenced.

Dependent Variables

In addition to an analysis of TOJ ability, the performance of subjects in the post-reaction task of indicating the nature of either of the signals was also of experimental interest. The ability of subjects to accurately give information about either the primary or auxiliary signals was a measure of the equalization of post-detection

processing in the two channels. In addition, similar to the previous two experiments, reaction time performance in the TOJRT condition was required to be in correspondence with associated CMPRT performance.

Preliminary Procedures

Simple reaction time data was collected to determine individual reaction time differences between the two sensory modalities and to provide familiarization with the apparatus. Due to the fact that the visual signal in the CMPRT and TOJRT conditions would randomly be either a red or an amber stimulus, simple reaction time data were collected for both conditions. Similarly reaction time performance was obtained for both the high and low frequency tones employed.

Experimental Design

Similar to Experiments I and II a mixed factor repeated measure design was employed to test for an attentional effect on TOJ ability.

Task

The experimental task required subjects to make a fast reaction to the primary signal as in Experiments I and II. Immediately after the response, the subject was verbally cued by the experimenter as to the modality in which he was to provide information. The subject's response to the cued modality was verbal. Reaction time feedback, but no TOJ or signal identification feedback, was provided. The experimenter cured either the visual or auditory modalities in random order. As in all other TOJRT conditions, a random half of all trials were catch trials to ensure selectivity of response to the primary signal.

Apparatus

In order to accommodate the presentation of two distinct signals within each sensory modality, the apparatus was necessarily modified. The Leecraft snaplight from Experiment II was replaced by a Sigma Instruments model 8L3-115 photo cell light source housing, with an 8 mm aperture. Under this aperture a diffusion lens was fixed to diminish any possibility of obtaining spatial information from the signal lights inside the housing. Within the light source housing, red, amber, and white Dialco, series 39, 6.3 volt indicator lights were situated so as to provide maximum illuminance through the aperture in the filter. A Hewlett-Packard 467A power amplifier supplied 10 volts of DC current to power the lights. Supplying current above the rated voltage of the neon lights provided clear visual stimuli with optimal signal detectability. The auditory stimuli were provided by means of an Eico Electronic Instruments model 377 audio generator. Either 750 Hz or 1500 Hz sinusoidal waves were used. The warning signals and the auditory cue, when appropriate, were white noise signals as in Experiments I and II. The white indicator light served as the warning signal and appropriate cue stimulus in the visual modality. Subjects' TOJ and signal identification responses were made verbally over a microphone-speaker circuit monitored by the experimenter.

Subjects

Six unpaid volunteer graduate students in physical education at the University of Alberta served as subjects. All were right-handed, had no *a priori* knowledge of the law of prior entry and had no previous experience in psycho-motor research.

Procedure

Except for changes discussed below, all procedures were identical to those employed in Experiments I and II.

Simple reaction time data were obtained for both stimuli within each sense modality. In these trials the usual preliminary warning and cue signals of white light and random noise were followed by either a red or amber light in the visual modality or a low or high tone in the auditory modality. Blocks of twenty trials with feedback for each of the four conditions were administered.

In the CMPRT condition, the light-tone combinations were semi-randomly presented in blocks of 20 trials. Sixty total CMPRT trials with feedback were given per modality in order to obtain 30 reaction time trials of each of the primary signals in combination with either of the auxiliary stimuli. In a similar manner, a semi-random presentation of the four light-tone combinations were given for the 60 TOJNO trials after the four 20-msec staircases were initiated. In the TOJAUD and TOJVIS conditions the same randomization schema was employed.

The procedure for a typical TOJAUD or TOJVIS trial was as follows: After the usual preliminary warning signal, appropriate primary stimulus cue, and final bi-modal warning signal, there was a variable delay. After this delay one of the light-tone combinations occurred (either low tone, red light; low tone, amber light; high tone, red light; or high tone, amber light). The ISI between the onsets of the two signals was determined by the status of the staircase employed on that particular trial. When the experimenter observed the digital readout on the reaction time clock (indicating the completion of the

reaction time response) he verbally indicated the modality randomly selected for that trial. Immediately thereafter the subject verbally reported the identity of the queried signal and its order. For instance, if the experimenter required information concerning the auditory signal, he would verbally indicate "Tone." A typical response by the subject might be "Low, first" or "High, last." If the experimenter were to query the subject as to the nature of the visual signal he would indicate "Light," to which a typical response might be "Amber, second" or "Red, first." The order in which subjects reported the information was not controlled. Approximately every 20 trials, subjects were asked to identify single tone signals in order to verify that the high and low frequency stimuli were still perceived as subjectively different. This procedure also provided a short rest interval during the TOJAUD and TOJVIS conditions.

RESULTS

Mean simple reaction time and standard deviations for both stimuli in each sense modality are given in Table X. Asymptotic performance in the simple reaction time task was assumed given that all within-modality mean scores were within one standard deviation. Table XI lists the mean CMPRT and TOJRT values and their associated standard deviations. With the exception of Subjects 3 and 4 in the TOJVIS condition, both of whom evidenced a slight (4 msec) increase, TOJRT performance was equal to or faster than associated CMPRT conditions, satisfying the optimal attention assumption of the concurrent TOJ-reaction time task.

Table X. Mean simple reaction time and standard deviations

		Auditory		Visual	
Subject		750 Hz	1500 Hz	Amber	Red
1	$\bar{x}$	214	192	258	274
	σ	22.5	27.1	12.4	15.7
2	$\bar{x}$	211	192	265	266
	σ	26.1	26.3	56.9	35.1
3	$\bar{x}$	213	219	304	311
	σ	30.6	28.4	33.1	43.6
4	$\bar{x}$	233	238	312	310
	σ	26.4	24.0	38.2	37.6
5	$\bar{x}$	203	209	281	284
	σ	32.5	30.2	27.1	27.9
6	$\bar{x}$	224	199	283	286
	σ	24.1	29.0	37.6	37.5

To determine subjects' ability to give accurate stimulus information and hence meet the requirement of equal post-detection processing in both sensory modalities, all erroneous responses were tabulated. Table XII lists the number of errors per condition by subject. There were nine total errors for all subjects giving a 1.25% average error rate over all conditions. Subjects 1, 4, and 6 provided errorless data,

Table XI. Mean complex and temporal order judgment reaction time

Subject		Auditory		Visual	
		CMPRT	TOJRT	CMPRT	TOJRT
1	$\overline{x}$	200	187	282	270
	σ	12.7	29.2	20.6	29.2
2	$\overline{x}$	201	196	265	238
	σ	24.5	39.7	47.9	51.3
3	$\overline{x}$	199	197	301	305
	σ	19.8	44.3	40.8	34.2
4	$\overline{x}$	249	247	312	316
	σ	25.6	32.7	30.2	26.8
5	$\overline{x}$	231	213	298	267
	σ	36.5	27.2	39.3	41.4
6	$\overline{x}$	240	233	310	289
	σ	56.3	45.3	59.4	41.3

and only Subject 2 made more than one errorful response in any one condition. Interestingly, seven of the nine errors occurred in the direction predicted were equal modality processing not evident; namely, three of five visual errors in the TOJAUD condition and four of four auditory errors in the TOJVIS condition. However, given the very small number of stimulus information errors, it was assumed that equal

Table XII. Error responses for stimulus information in TOJAUD and TOJVIS conditions (360 trials per condition)

	TOJAUD Signal Interaction								TOJVIS Signal Interaction							
	Amber/Low		Red/Low		Amber/High		Red/High		Amber/Low		Red/Low		Amber/High		Red/High	
	Queried Modality								Queried Modality							
Subject	Light	Tone	Light	Tone	Light	Tone	Light	Tone	Light	Tone	Light	Tone	Light	Tone	Light	Tone
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	1	0	0	2	0	0	1	0	0	0	0	0	0
3	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Σ	1	0	0	1	0	1	2	0	0	1	0	0	0	1	0	2

post-detection processing was optimally undertaken within each sensory modality.

Using standard probit analyses, points of subjective simultaneity were computed for each subject. Table XIII gives the PSS scores for each attentional condition as well as the individual and mean prior entry effects. Contrary to the prediction postulated by an equal post-detection processing model, a massive mean prior entry effect of 116 msec surfaced. Similar to Experiments I and II, one subject also provided data which showed a reversal tendency. Figure 18 graphically illustrates

Table XIII. Points of subjective simultaneity for TOJAUD and TOJVIS conditions (msec)

Subject	TOJNO	TOJAUD	TOJVIS	Prior Entry Effect
1	-89	-190	-4	186
2	-36	-116	+48	164
3	-136	-162	+41	203
4	-56	-106	-116	10*
5	-13	-43	-27	16
6	-112	-140	0	140
$\bar{x}$	-74	-126	-10	116

Mean prior entry effect: 116 msec

*Reversal effect

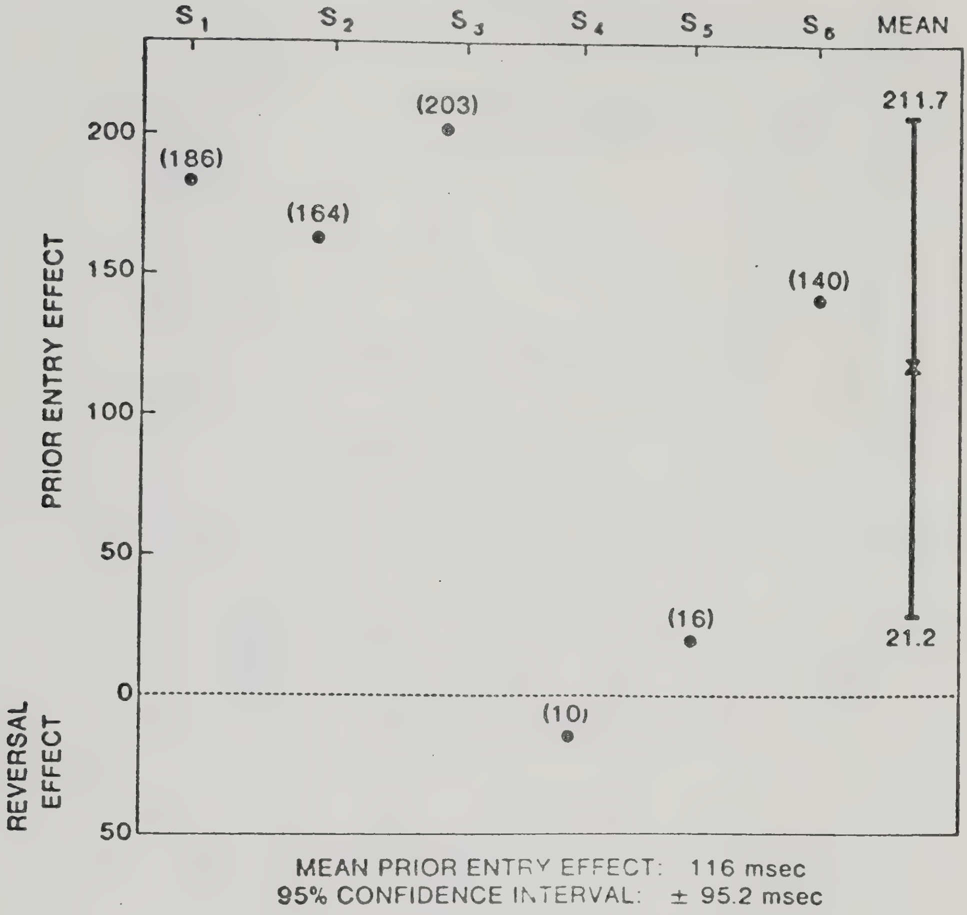


Figure 18. Individual and mean prior entry effects

the inter-subject PSS variance and the 95% confidence interval about the mean point of subjective simultaneity. Unlike Experiments I and II, the prior entry effect was sufficiently large enough to preclude the lower confidence interval boundary crossing into the reversal effect segment of the figure. Figures 19 through 21 provide individual psychometric functions for each subject per attentional condition.

A repeated measure ANOVA was computed to test for differences of PSS data between the TOJAUD and TOJVIS conditions. Contrary to the results of Experiments I and II, there was a significant difference between the points of subjective simultaneity of the different attentional conditions ($F_{(1,4)} = 9.86$, $p < .05$). A significant prior entry

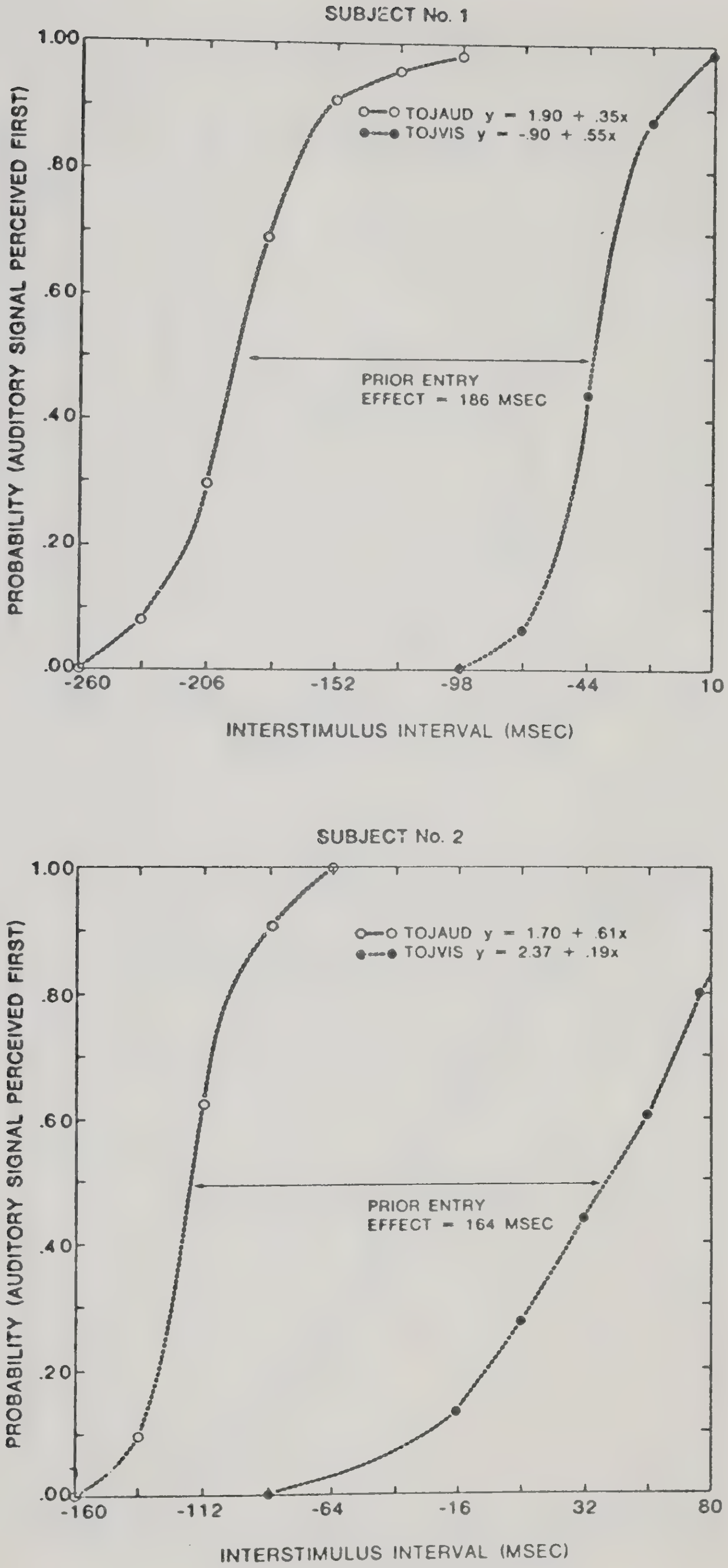
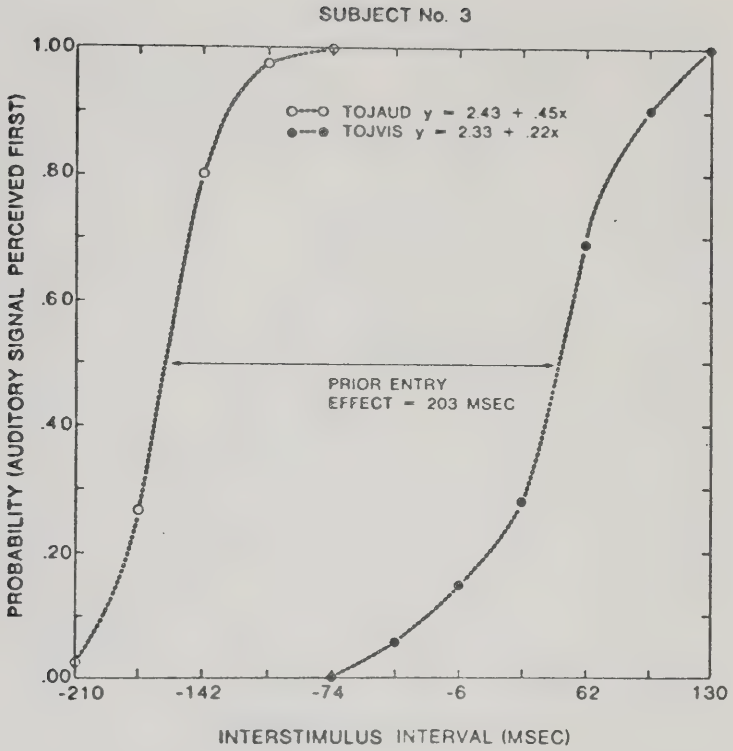


Figure 19. Psychometric functions for TOJAUD and TOJVIS conditions (Subjects 1 and 2)



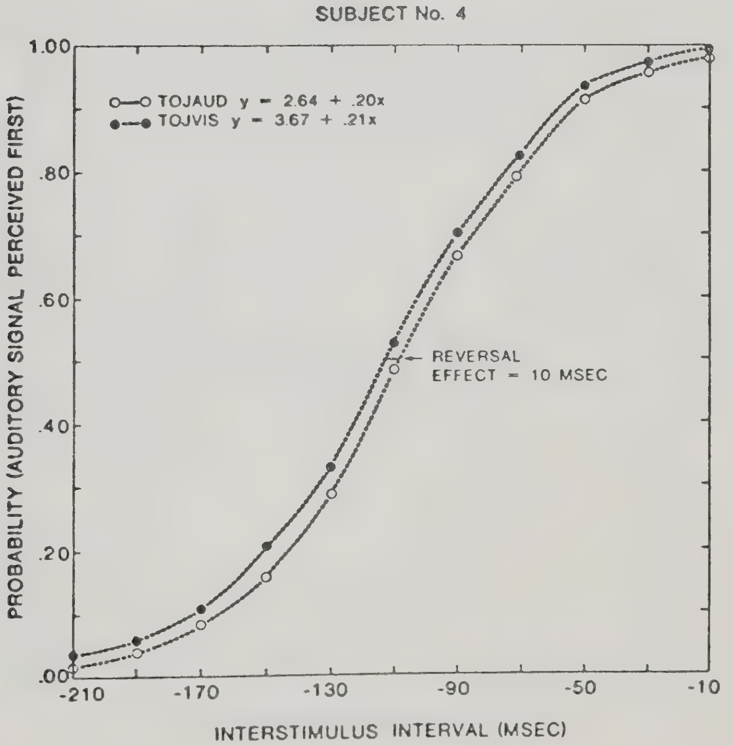
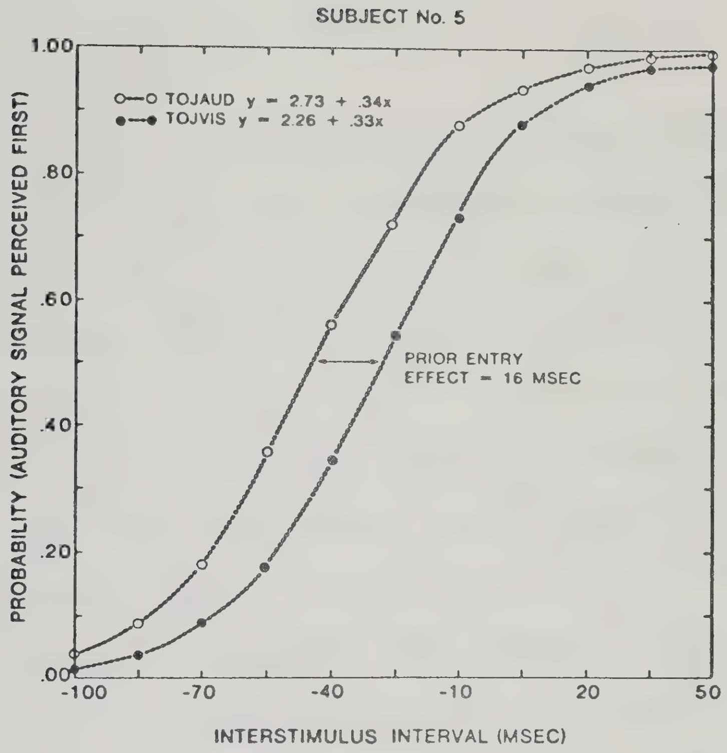


Figure 20. Psychometric functions for TOJAUD and TOJVIS conditions (Subjects 3 and 4)



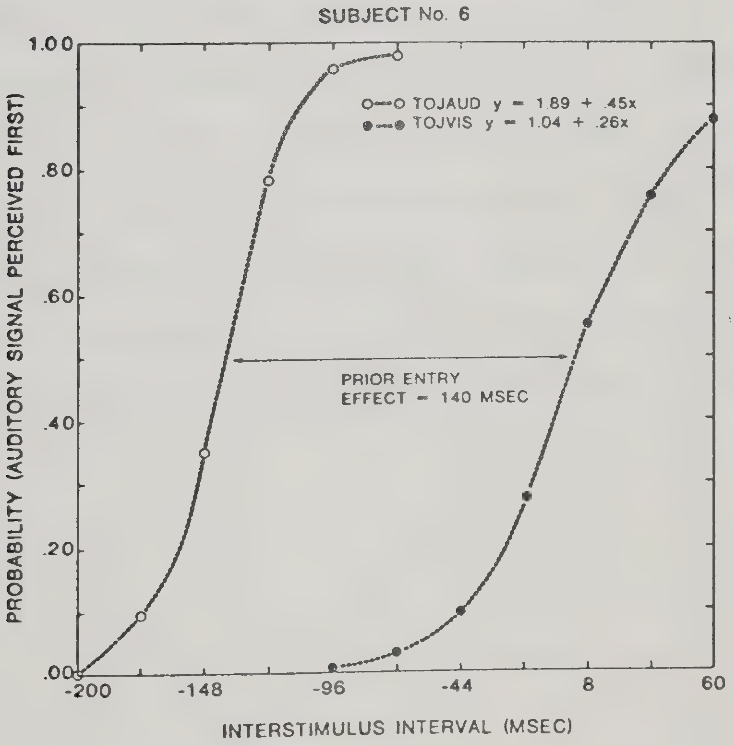


Figure 21. Psychometric functions for TOJAUD and TOJVIS conditions (Subjects 5 and 6)

effect had been realized.

Two conditions had been necessary to meet the requirements of biased attention and equal post-detection processing. First, TOJRT performance was required to be equal to or faster than the corresponding CMPRT condition. This satisfied the requirement that attention was optimally selective to the primary signal. Second, stimulus information errors were required to be minimal regardless of the locus of attention. This requirement insured that the subject necessarily processed both signals equally. Both of these conditions were met in Experiment III, yet the prediction of a minimal or even non-existent prior entry effect, as suggested by the equalized channel processing model (see Figure 17) was not realized. In fact, contrary to expectation, the prior entry effect attained statistical significance. This finding seriously undermined the hypothesis that unequal signal processing was responsible for the prior entry effects previously reported. Coupled with the fact that the effect has been tentatively shown not due to pre-detection processes in the sensory channels (Sternberg, et al., 1971), it was tentatively hypothesized that the locus of the perceptual bias might be associated with processes subserving response execution.

CHAPTER IV

DISCUSSION

The law of prior entry was described by Titchener (1908) as follows:

> The stimulus for which we are predisposed requires less time than a like stimulus, for which we are unprepared, to produce its full conscious effect. Or, in popular terms, the object of attention comes to consciousness more quickly than the objects that we are not attending to (p. 251).

Experiments I and II provided data that revealed a prior entry trend in TOJ perception, although statistically the results were insignificant. It was concluded, however, that the mean perceptual shift of 30 msec was of experimental interest in that in any high-speed perceptual motor task involving decisions concerning the relative occurrence of heteromodal stimuli, a stimulus-specific differentiation in perceptual processing leads to a characteristic decisional bias in the direction of the differentially treated stimulus. Such a decisional bias was viewed as not only of theoretical but practical importance. The main thrust of the final experiment was to investigate the actual locus of the prior entry phenomenon in the left-to-right model of the human operator illustrated in Figure 3. Results by Sternberg, et al. (1971) provided evidence against the hypothesis that the effect was due to mechanisms on the signal detection side of the model. Experiment III was designed to test the hypothesis that the cause of the prior entry trend in the data was due to the more central or processing aspect of the human operator. Specifically, it was

assumed that the effect was due to unequal post-detection processing of the two signals. When task demands required a more equal processing of the stimuli, however, instead of the effect being attenuated, it was augmented. Two post hoc explanations for this result are offered.

Unequal Channel Processing Bias

It may be possible that the processing demands of the two signals were not, in fact, equated. Figure 16 depicts the effect of unequal channel processing on TOJ performance. In this model, the unequal post-detection processing in Channel X is due to the fact that the signal not only conveys its onset information, but also the directive for response execution. This response-directive bias was hypothesized as requiring more of the central processing capacity of the operator (Moray, 1967; Kahneman, 1973) and hence allowed the attended signal more favorable processing. It was hypothesized that this additional processing was responsible for a biasing effect on the subjective judgment of signal onset order. Figure 17 shows the counter-balanced processing model in which the two signals in the TOJ task are afforded theoretical processing equality. It was the assumption in this model that, when information about both signals was required, the processing necessary to subserve the identification task would optimally counterbalance the hypothesized response-directive effect. It was assumed that in such a high-speed task, the additional problem of identifying either of the signals would likely require so much processing capacity that there would be no remaining "space" (Keele, 1973) in which the response-directive effect could operate; or so little space that the

effect would be minimized, thus attenuating or completely negating the concomitant prior entry phenomenon. It is quite possible, however, that the stimulus identification task was not sufficiently demanding of the limited capacity system to completely minimize the effect of the response-directive processing of the attended stimulus. If this were true, it would be expected that the prior entry trend would not only be evident, but that it would be larger than that evidenced in Experiments I and II due to a general reduction in TOJ ability caused by the increase in total processing due to the additional stimulus identification task. This post hoc explanation for the large prior entry effect in Experiment III is attractive in that there were so few errors in the stimulus identification task, suggesting that the task demands may not have taxed the central processor to the extent of minimizing or completely negating the hypothesized response-directive effect. Figure 22 depicts the possible effect on TOJ performance when unequal channel-specific processing is embedded in a task requiring an overall increase in central processing. In this model, despite the fact that the decision center received equal influence from each channel in the processing of stimulus information, the response-directive processing effect is viewed as the determining source of the perceptual bias leading to the prior entry effect. Underlying this model, and the related hypothesis explaining the prior entry effect, is the notion that the greater the central processing demands of the task, the greater will be the prior entry effect given any unequal channel-specific processing. The temporal order judgment center is viewed as a mechanism highly sensitive to any unequal biasing by nature of the task demands.

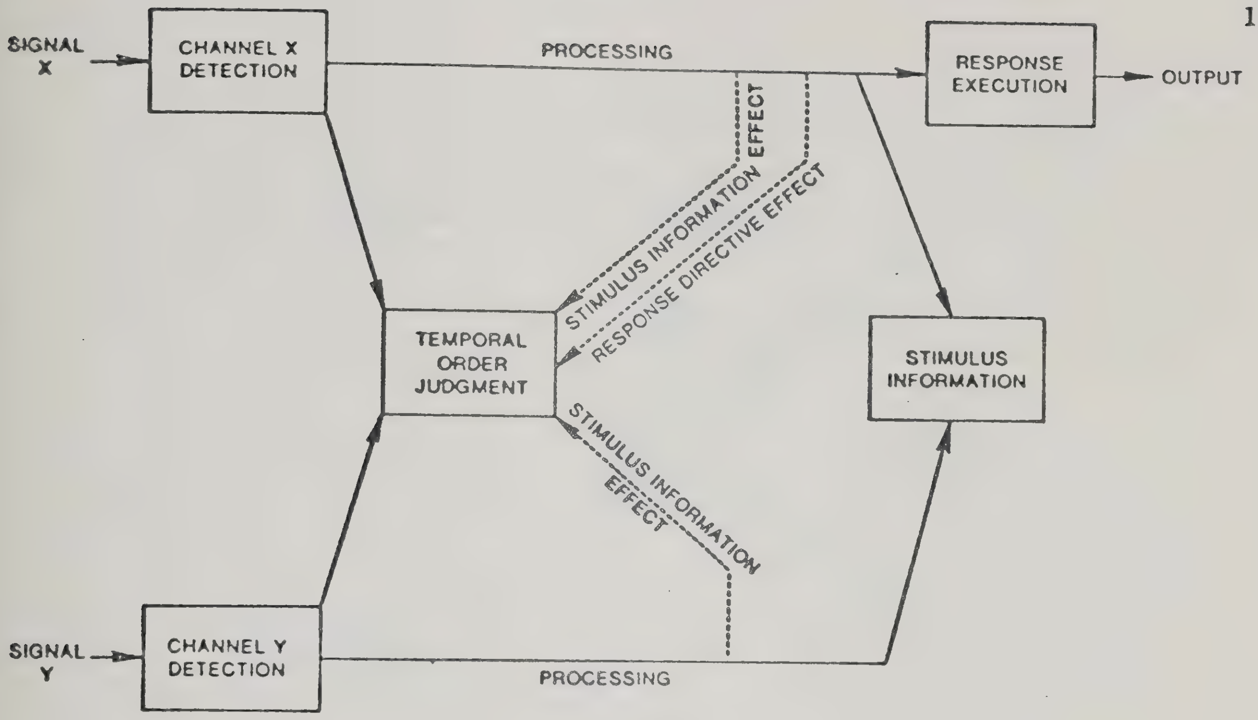

SIGNAL X
CHANNEL X DETECTION
PROCESSING
RESPONSE EXECUTION
OUTPUT
EFFECT
STIMULUS INFORMATION
RESPONSE DIRECTIVE EFFECT
TEMPORAL ORDER JUDGMENT
STIMULUS INFORMATION
STIMULUS INFORMATION
EFFECT
SIGNAL Y
CHANNEL Y DETECTION
PROCESSING

Figure 22. The effect of unequal channel processing and temporal order judgment performance in a task requiring an overall increase in central processing

Response Execution Bias

There remains an alternative, post hoc explanation for the prior entry phenomenon. It is possible that the actual response execution to a specific signal may be the cause of the perceptual bias subserving the prior entry effect. Figure 23 depicts an hypothesized response execution influence upon temporal order judgment performance. Unlike the previous model describing the locus of the prior entry effect, this model is not dependent upon an unequal channel-specific processing assumption. In this view of the sequencing of signal processing, the TOJ center is equally affected by detection and subsequent stimulus information inputs from both channels. The cause of the characteristic perceptual bias is due to the actual overt response to one of the signals. Within the theoretical parameters of this model, then, the

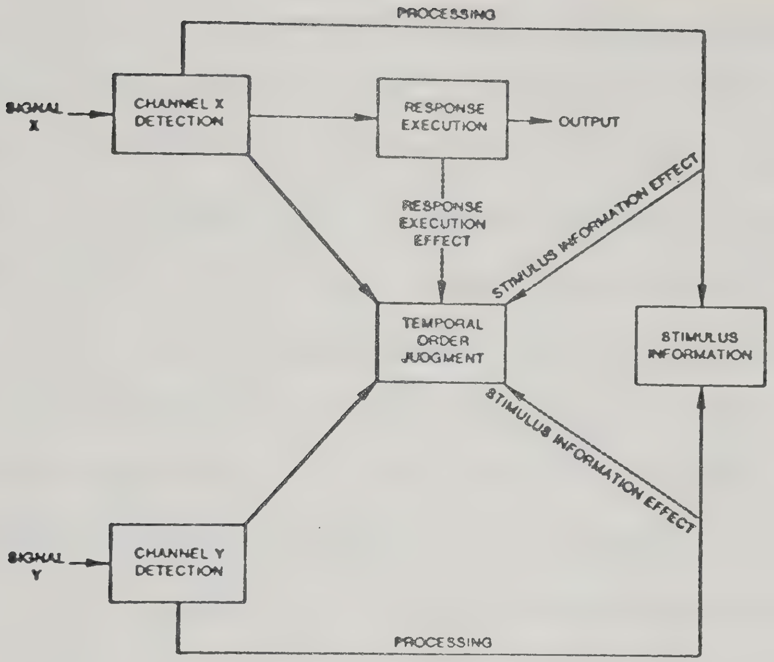

PROCESSING
SIGNAL X
CHANNEL X DETECTION
RESPONSE EXECUTION
OUTPUT
RESPONSE EXECUTION EFFECT
STIMULUS INFORMATION EFFECT
TEMPORAL ORDER JUDGMENT
STIMULUS INFORMATION
STIMULUS INFORMATION EFFECT
SIGNAL Y
CHANNEL Y DETECTION
PROCESSING

Figure 23. The effect of response execution and temporal order judgment performance

prior entry effect is due not to unequal signal processing as originally hypothesized in Experiment III, but to unequal response execution.

In dealing with the concept of focalization or selective attention in his provocative book on the evolutionary foundations of psychology, Goodson (1973) has suggested that if material competing for attention is sufficiently pervasive, another input that might be brought into focus under other circumstances will not be perceived and will consequently not be encoded. According to Goodson "when other factors are constant, the greater the tendency for a partial presentation to result in focusing on a fused encode, the more likely it is that the partial presentation will be apperceived as the total item (p. 130)." Goodson's thesis is that any particular component of sensation or memory that is in focus at any given moment is always the one that has provided

the most enduring and relevant survival information in the total history of the organism (both as species and as individual). Viewing the human operator in this context, it is suggested that an actual overt response may be the dominant input affecting the perception of temporal order. Certainly it may be argued that the responses that an organism elicits as a function of environmental demands are of utmost "survival" interest to the longevity of the organism. If the sensory input resulting from the consequences of an overt response are, indeed, pervasive, it is possible that such input dominates the perception of closely preceding temporal events. When it is remembered that the staircase procedure provided ISIs that were predominantly centered around the subject's point of subjective simultaneity, thus providing signal onsets in the region of maximal temporal order uncertainty, the implication of an effect of the sensory consequences of a response to one of the stimuli is strengthened. The fact that feedback was provided to only one component of the experimental task, namely reaction time performance, further adds to the implication of a response execution bias in perception. Subjects were instructed to provide the fastest reaction time data possible throughout all experimental conditions and were led to believe that the variable of major concern was the ability to maintain optimum reaction time performance. In this regard, it may be assumed that the subjects' greatest concern in the experimental task was to provide optimal response integrity. This assumption is not unwarranted in view of the fact that reaction time performance remained fast and stable throughout all experimental conditions. In the context of the evolution-based theory proposed by Goodson, it may

be stated that the locus of any homeostatic disequilibrium of the operator when faced with the concurrent temporal order judgment-reaction time task was probably associated with the requirement to react optimally. Goodson suggests that "The more ambiguous the sensory input, the more likely such components are to be apperceived in relation to the existing disequilibrium state (p. 132)." This corollary of focalization is based not only upon anecdotal evidence (ie, a hungry individual perceiving ambiguous objects as food, and one sexually deprived tending to perceive sexual items in the same situation), but also upon experimental evidence such as investigations by Ansbacher (1973), Stephens (1931, 1936) and Bruner and Goodman (1947) that have reported a biasing effect of disequilibrium or organismic need on the perception of size and numerosity. If it is assumed that the complicating sensory input of two closely successive stimuli is somewhat ambiguous in nature, at least at ISIs in close proximity to the subject's point of subjective simultaneity, it is reasonable to assume that the perception of the temporal order of such events may be biased by the component of the task that is most compatible with the subject's disequilibrium reduction, namely the response to the primary signal.

Werner and Wapner (1952), in discussing their sensory-tonic field theory of perception, allude to the same point. These investigators provide data suggesting that perception is organismic in nature; that the organism's states are part and parcel of perception and that any stimulus object always arouses sensory-tonic events (ie, events which involve the total state of the organism at the moment of stimulation). In this regard, the fact that the reaction to a primary

stimulus was the only differentiation between the subjective treatment of the two closely successive signals in the order judgment-reaction time task, the response execution bias hypothesis as a post hoc explanation for the prior entry effect appears warranted.

Along this same line of reasoning, Ashby (1962) has suggested that the amount of selective action that the brain can achieve is absolutely bounded by its capacity as a channel. In explaining the implications of what he terms the law of requisite variety (Ashby, 1968), he indicates that the outcome of any interaction of an individual and his environment is related to the specific response of a set of responses that the individual makes in any given situation. To Ashby the variety in an organism's response repertoire is the crucial variable in dealing with the variety of possible outcomes that could in fact occur as a result of specific environmental conditions. Ashby's concept of response and stimulus variety was delivered in the context of general systems theory, thermodynamics, and biological equilibrium and, as such, may be extended to a discussion of the perceptual performance of the human operator. The law of requisite variety maintains that "only variety can destroy variety (p. 135)." In effect a major tenet of the law is that any outcome involving a biological system is dependent upon the responses that the system is willing to make. The more extensive the response alternatives an organism has available, the greater the probability of matching the variety of an environmental situation. In short, the outcome of any environmental-response interaction is influenced by the action that the operator chooses from his response variety. In the concurrent temporal order judgment-reaction

time paradigm, the primary task requires one of two possible responses: react to the primary stimulus on reaction trials or inhibit a response to the auxiliary signal on catch trials. In the latter case, the outcome of the temporal order judgment is unity by default; however, in the reaction trials, the perception of temporal order is less than perfect in relation to the objective state of the sensory conditions. Judgments in this condition have been over-represented by subjective indications favoring the signal to which a response was initiated. In the terms of Ashby's requisite variety, the perceptual outcome appears to be a function of the response that the organism is willing to make.

When viewing the perceptual phenomenon under consideration in light of the models of Goodson (1973), Werner and Wapner (1952) and Ashby (1962, 1968), it appears that a response execution bias hypothesis as a post hoc explanation for the prior entry effect may be justifiable.

Of interest,however, is the fact that the prior entry phenomenon was evident in the earlier studies (von Tchisch, 1885; Angell & Pierce, 1891; Stevens, 1904; and Stone, 1926) in which a concurrent reaction time task was not required. If the response initiation information carried by the primary signal or the actual overt response to the primary signal is theorized as the cause for the prior entry effect, how is the phenomenon to be explained within the context of these "non-reaction" studies? A possible explanation is offered by Frey & Wilberg (1975) who suggested that the locus of the prior entry effect in the earlier studies may have been due to the subjects' a priori knowledge

concerning the prior entry law. An alternative point of view has been discussed. Geiger (1902) and Dunlap (1920) have both suggested that the prior entry phenomenon was due to artifacts associated with the earlier complication clock. As appealing as the evidence provided by these investigators appears to be, however, the apparatus artifact hypothesis does not account for data resulting from the discrete bi-modal presentations used in the Stone (1926) study. In this, the strongest support for Titchener's law prior to the Sternberg, et al. (1971) investigation, there was a mean prior entry effect of approximately 50 msec; yet, no reactions were required. Despite the fact that discrete stimuli presentations undermine the Dunlap (1920) and Geiger (1902) hypotheses, there remains the possibility that the *a priori* knowledge of subjects in the Stone (1926) study may have contaminated the results of that investigation. Similarly, confounding variables cloud the issue of perceptual bias in the Sternberg, et al. (1971) experimentation. In that study, the first to give support to both the proposed response directive and the response execution hypotheses, there was also the possibility that *a priori* familiarity of the subjects concerning the law of prior entry, may have been responsible for the characteristic prior entry effect evidenced. The methodology employed in Experiment III avoided the potential artifacts described by Geiger (1902) and Dunlap (1920) as well as the confounding *a priori* variable described by Frey & Wilberg (1975).

These possible explanations for the significant effect evidenced in Experiment III may be rejected. Sternberg, et al. (1971) have provided evidence that perceptual processes in the channels themselves should not be implicated in the prior entry effect; and an analysis of the stimulus

identification performance of subjects in Experiment III indicated that unequal signal processing was likewise an untenable explanation for the temporal order judgment performance evidenced. Clearly, the remaining alternative as an explanation for the prior entry effect appears to be associated with the response component of the TOJ-reaction time task.

Future experimentation in the area of temporal order perception must focus upon the interaction of total processing demands, pre-reaction stimulus cueing effects, and response execution biasing. Of primary importance is an understanding of the interaction of total processing demand and the experimental task employed. It may become evident that the prior entry effect is a monotonic function of total processing demand regardless of the perceptual or response loaded nature of the task. Likewise it may be shown that the phenomenon is positively correlated with subjective expectation of specific ISI combinations, actual speed of response, or even sequential dependency of preceding trial performances. Experimentation along these lines is presently underway.

Conclusion

The prior entry effect has been substantiated as a valid perceptual phenomenon. In this regard the initial hypothesis of this study, that the "law" of prior entry was a questionable doctrine and that temporal order perception would not be affected by the locus of attention, was rejected. The most conclusive statement that can be made concerning the prior entry phenomenon as a result of the present series of experiments is that the effect seems to be enhanced by an

increase in the total processing demands of the task employed. At this time an unequivocal interpretation of the exact locus of the process subserving the phenomenon can only be suggested. Further investigations must be addressed to the delicate unconfounding of the response directive and actual response execution bias hypotheses proposed above. Also of interest is the effect of primary stimulus cueing under variable conditions of total task processing when no actual overt responses are required. Of extreme importance in future studies of the prior entry phenomenon is the employment of methodological metrics sensitive to the variables of attention and consciousness. It may become evident that reaction time as a measure of attention and order judgment as a measure of consciousness are not the most robust indices of these crucial variables.

Lawther (1977) in discussing competitive athletics has suggested that "sport strategy usually aims at creating inaccurate perceptions, temporary illusions, wrong decisions as to action, and often involves the attempt to perform the unexpected (p. 76)." Hebb (1961) described the nature of learning in the adult as not a process of learning to make specific movements, ". . . but learning a relationship, an association, between perceived environmental events. This makes adult learning primarily perceptual. . . (p. 156)." Understanding precisely what affects this perceptual fidelity will undoubtedly enhance an understanding of the perceptual-cognitive-volitional interface in human skill acquisition and performance. In this regard, and especially in view of the response-implicated models suggested by Goodson (1973) and Ashby (1962, 1968), future experimentation must be focused on the hypothesis that

the prior entry doctrine may be a special instance of a more general perceptual-response law that implicates a broad interaction of overt behavior (or the intention of such) and subjective perception. Understanding the relationship between the operator's response variety, the probability distribution of discrete motor responses, and the subjective interpretation of sensory events is viewed as the most important next step toward a total understanding of the human performer. If it can be shown that perception is mediated by the responses that the operator evokes in a given environmental situation, the role of the physical educator, athletic coach and behavioral scientist will be more clearly delineated in the quest for optimal psycho-motor expression.

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APPENDICES

APPENDIX 1

ANALYSIS OF VARIANCE FOR A REPEATED MEASURE DESIGN WITH TWO TREATMENTS

Edwards (1972) has shown that when only two treatments are of experimental interest in a repeated measure design the t test is appropriate for testing for a treatment effect. In this case:

$$t = \frac{\bar{X}_{.1} - \bar{X}_{.2}}{S_{\bar{D}}}$$

where

$$S_{\bar{D}} = \sqrt{\frac{\Sigma (D-\bar{D})^2}{b(b-1)}}$$

and

D_1 = difference between treatment 1 and treatment 2 for block (subject) 1

D_2 = difference between treatment 1 and treatment 2 for block (subject) 2, etc., and

b = number of blocks (subjects).

According to Edwards (1972), $t^2 = F = MS_T/MS_{ST}$ and this value of F should be tested using a reduced number of degrees of freedom. As Geisser & Greenhouse (1958) have shown, the most conservative number of degrees of freedom may be obtained by multiplying the reciprocal of the degrees of freedom for the repeated measure variable, or

$\epsilon = \frac{1}{t-1}$, by the normal degrees of freedom

t-1 and (S-1) (t-1), where t = number of treatments and S = number of subjects. Due to common violations of assumptions of homogeneity of variance and equal correlations, this reduced degrees of freedom guards against a Type 1 error. As Edwards (1972) points out, however, when only two treatments are tested "the degrees of freedom for evaluating F remain unchanged for a 'conservative' test (p. 275)."

APPENDIX 2

TAPE RECORDED INSTRUCTIONS FOR EXPERIMENTAL CONDITIONS

Experiment I

INTRODUCTION

Thank you for participating in this study. Your cooperation is very much appreciated.

The main thrust of this experiment deals with the latency in responding to two distinct stimuli: an auditory signal delivered through headphones and a cutaneous signal, mild electric shock, delivered to the forearm.

The first thing that we'll do today is introduce you to the apparatus, obtain threshold values for just being able to hear the auditory signal and for being just able to feel the cutaneous stimulus, a cross-modality match which I will explain later, and finally some actual reaction times. After the threshold values and cross-modality match have been obtained and just prior to the reaction time task, more information and instructions will be given.

* * * * * * * * * * * *

Simple Reaction Time - Auditory

The reaction time task requires you to perceive the onset of the appropriate signal and, as soon as possible, to pull the small lever before you on the table. Your fingers may rest softly against the lever but it should not be moved until the signal is actually perceived as this

will automatically abort that particular trial. In the first series of trials you will be reacting to the onset of the auditory signal. Prior to the onset of the noise signal, preliminary or warning stimuli will occur to prepare you for your response. The sequence of these preliminary signals is as follows. First you will receive a half second of both the auditory and cutaneous signals together, then there will be a half-second of no stimulation. Next comes a half second of the auditory signal alone. This signal serves as a reminder that you are responding to the auditory stimulus. After this signal there will again be a half second of no stimulation, followed by a very short onset of both signals together. At this point there will be a variable delay and sometime during this short delay interval, the auditory signal will occur again. As soon as it does your response is required. To summarize then: both signals occur together for a half second, followed by a half second of nothing, followed by a half second of the auditory signal alone, this followed by another half second of nothing, followed by a very brief onset of both signals together.

Then there is a variable delay and when the noise occurs again you are required to respond as quickly as possible by pulling the lever. When the lever is pulled it stops the signal and a clock that begins when the signal onset first occurs. This time will represent your reaction time for that trial and as soon as it is recorded and the variable delay changed another trial will occur.

On a random half of all the trials no signal will occur and on these trials you, of course, will withhold your response. These trials are inserted to ensure that you are actually responding

selectively to the signal.

There will be 5 practice trials to familiarize you with the preliminary signals and the mechanics of the reaction time lever. There will be a total of 80 reaction time trials with a short rest after the first 40. You will be given feedback on your performance in all subsequent sessions; however in this, the first session, no information will be given concerning your reaction time performance. You are requested to always rest your fingers against the lever the same way from trial to trial, to keep your finger movements as constant as possible. And of course, you are requested to react as fast as you possibly can when the auditory signal is first perceived. Any time that you wish to interrupt the testing for any reason, remove your headset and tap on the window before you. If you wish to interrupt a particular trial once it has been initialed, simply pull the lever and this stops everything. Do you have any questions?

* * * * * * * * * * * *

Simple Reaction Time - Cutaneous

You have completed the auditory reaction time portion of the study and as you may have expected you are now required to react selectively to the cutaneous signal. As before there will be a series of preparatory signals before your reaction is required. In the next few trials these signals will be as follows: both auditory and cutaneous signals together, a pause, then the cutaneous alone, a pause, and then both signals together again briefly. After a variable delay, then, the cutaneous stimulus will occur and you are required to react as

quickly as possible when it does. If you have any questions, please ask them now.

Complex Reaction Time Task

In the next section of the study you will be required to react to one of the signals as you have in the past, however, in close temporal proximity another signal will also be presented. The other signal, which will be called the auxiliary signal, is to be ignored and only the signal to be reacted to, called the primary signal, should receive your attention. The primary signal will remain constant for the entire session. For example, the primary signal may be the cutaneous stimulus for a session. In this case you would receive the usual preliminary signals, that is, both together , then the primary stimulus alone, and then both together again. Then, after a variable delay, the cutaneous signal will occur again and your response is required. The difference in this task, however, is that either just before or just after the primary cutaneous signal, the auxiliary auditory stimulus will occur. This signal is to be ignored and reactions are only to be made to the primary or cutaneous signal. A random half of all trials will be catch trials. On these trials only the auxiliary signal will occur and reactions on these trials will be penalized by a point system. Due to the concentration required in this task there will only be 20 reaction trials presented. Maximum effort will be required to maintain optimal performance in this task. Reaction time feedback will be provided during these trials. If you have any questions please ask them now.

Temporal Order Judgment Task

In the next section of the study you will not be required to give a fast reaction to one of the signals. Instead, you are asked to passively observe the preliminary warning signals and then the onset of the two stimuli. After the two signals have been extinguished by the experimenter you are then required to indicate which of the two stimuli you perceived as occurring first. You will make your decision known by depressing the appropriate button before you, labeled "ARM" or "EAR." Because there is no primary or auxiliary signal in this condition of the study there will not be a cue stimulus given during the preliminary warning signals. In other words the progression of events will be as follows: both signals will occur for a half second, then there will be a blank period of one and a half seconds, followed by a brief onset of both signals together. Then there will be a variable delay after which the two signals will occur again at various interstimulus intervals. After they have been extinguished you are to indicate which stimulus occurred first. Two blocks of twenty trials will be administered with no feedback provided as to the accuracy of your judgments. Do you have any questions?

(After the original 40 TOJNO trials were obtained, four interleaved staircases were begun and 60 final TOJNO trials were administered. Instructions in this final session were identical to the above. They were given verbally by the experimenter.)

Concurrent Temporal Order Judgment -
Reaction Time Task

Congratulations, you have survived this experiment to the final section. In the last task you will be required to react selectively to the primary signal while ignoring the auxiliary stimulus. This is identical to the task that you have just completed. The only difference is that after you have made your reaction you will be asked to indicate which signal you think occurred first. In other words, the final task is a combination of the reaction time and judgment tasks which you have already completed. Obviously another dimension has been added to the reaction time task and it will require sustained concentration if stable reaction performance is to be realized. Throughout these trials reaction time feedback will be provided to inform you of your performance. No information will be given concerning the order judgments as this is merely a subsidiary task. You are, however, requested to make your judgments as accurate as possible and if you are unsure as to the order of the two signals to force a guess. Remember that a random half of all trials will be catch trials in which the auxiliary signal will occur alone. Don't get caught on these trials. The best way to ensure a good performance is to concentrate on the appropriate signal and only worry about one trial at a time. If you have any questions please ask them now.

Experiment II

INTRODUCTION

Thank you for participating in this study: Your cooperation is very much appreciated.

The main thrust of this experiment deals with the latency in responding to two distinct stimuli: an auditory signal delivered through headphones and a visual signal delivered via a small neon light.

The first thing that we'll do today is introduce you to the apparatus, ask you to match the intensities of the light and sound for equal strength, and then obtain some actual reaction times. After we equalize the light and sound for subjective equality and before the actual reaction time task more information and instructions will be given.

Simple Reaction Time - Auditory

The instructions in this condition were identical to those in Experiment I with the exception that the word "visual" was substituted for the word "cutaneous."

Simple Reaction Time - Visual

The instructions in this condition were identical to the same condition in Experiment I with the same exception as explained in the paragraph above.

Complex Reaction Time Task

The instructions in this condition were identical to the instructions in the same condition in Experiment I with the same exception as noted in the two previous paragraphs.

Temporal Order Judgment Task

The instructions in this condition were identical to the instructions in the same condition in Experiment I with the exception that the word "Arm" was replaced with the word "Eye."

Concurrent Temporal Order Judgment - Reaction Time Task

The instructions in this condition were identical to the instructions in the same condition in Experiment I.

Experiment III

INTRODUCTION

Thank you for participating in this study. Your cooperation is very much appreciated.

The main thrust of this experiment deals with the latency in responding to four distinct stimuli: a low and a high frequency tone delivered through headphones and a red and amber light delivered via a small visual apparatus.

The first thing that we'll do today is introduce you to the apparatus, ask you to adjust the loudness of the tones so that they match the brightness of the lights, that is, so that neither the lights nor the tones "overpower" each other, and finally obtain some actual reaction times. After the intensity adjustments have been made and prior to the reaction time task, more information and instructions will be given.

Simple Reaction Time - Auditory

The reaction time task requires you to perceive the onset of the appropriate signal and, as soon as possible, to pull the small lever before you on the table. Your fingers may rest softly against the lever, but it should not be moved until the signal is actually perceived as this will automatically abort that particular trial. In the first series of trials, you will be reacting to the onset of the low frequency tone. Prior to the onset of this signal, preliminary or warning stimuli will occur to prepare you for your response. The sequence of these preliminary signals is as follows: First you will receive a half

second of both an auditory and visual signal. These stimuli will be a medium frequency tone and a white light, respectively. After these signals are extinguished there will be a half second of no stimulation followed by a half second of the auditory signal alone. This single medium frequency stimulus is to remind you that you are to respond to an auditory signal on that particular trial. After this signal there will again be a half second of no stimulation, followed by a very short onset of both warning signals together. At this point there will be a variable delay and sometime during this delay interval, the low frequency auditory signal will occur. As soon as it does your response is required. To summarize then: both a neutral auditory and visual signal occur together for a half second, followed by a half second of nothing, followed by a half second of the auditory signal alone, this followed by another half second of nothing, followed by a very brief onset of both warning signals together. Then there is a variable delay and when the low frequency tone occurs you are required to respond as quickly as possibly by pulling the lever. When the lever is pulled it stops the signal and a clock that begins when the signal onset first occurs. This time will represent your reaction time for that trial and as soon as it is recorded and the variable delay changed another trial will occur.

On a random half of all the trials no signal will occur and on these trials, of course, you will withhold your response. These trials are inserted to ensure that you are actually responding selectively to the signal. There will be 5 practice trials to familiarize you with the preliminary signals and the mechanics of the

reaction time apparatus. There will be a total of 40 reaction time trials with a short rest after the first 20. You will be given feedback on your performance in all subsequent sessions; however, in this, the first session, no information will be given concerning your reaction time performance. You are requested to always rest your fingers against the lever the same way from trial to trial, to keep your finger movements as constant as possible. And, of course, you are requested to react as fast as possible when the auditory signal is first perceived.

Any time that you wish to interrupt the testing for any reason, remove your headset and tap on the window before you. Do you have any questions?

* * * * * * * * * * * *

You have completed the low frequency aspect of the auditory reaction time task. Next you will perform the same task but, after the preliminary warning signals, you will be presented with the high frequency stimulus. Remember that half of all trials will be catch trials in which no signal occurs. Unless you have any questions we will now proceed with 40 high frequency trials. Any questions?

Simple Reaction Time - Visual

You have completed the auditory reaction time portion of the study and as you may have expected you are now required to react selectively to a visual signal. In the first series of trials you will be required to react to the amber stimulus. As before there will be a series of preparatory signals before your reaction is required. In the next few trials these signals will be as follows: both the

auditory and visual signals together, a pause, then the visual alone, a pause, and then both signals together again briefly. After a variable delay, then, the amber stimulus will occur and you are required to react as quickly as possible when it does. If you have any questions please ask them now.

* * * * * * * * * * * *

You have completed the amber stimulus aspect of the visual reaction time task. Next you are required to perform the same task with the red visual stimulus. As before you will be presented the same preliminary warning and cue signals and a random half of all trials will be catch trials. Do you have any questions?

Complex Reaction Time Task

In the next section of the study you will be required to react to one of the signals as you have in the past, however, in close temporal proximity, another signal will also be presented. The other signal, which we will call the auxiliary signal, is to be ignored and only the signal to be reacted to, the primary signal, should receive your attention. The primary signal will remain constant for an entire session. For example, the primary signal may be the visual stimulus for a session. In this case you would receive the usual preliminary signals, that is, both together, the neutral visual signal alone, and then both together again briefly. Then after a variable delay, one of the visual signals (ie, red or amber light) will occur and your response is required. The difference in this task, however, is that

either just before or just after the primary visual signal, one of the auxiliary auditory stimuli will occur. This signal is to be ignored and reactions are only to be made to the primary or visual signal. A random half of all trials will be catch trials. On these trials only the auxiliary modality will occur and reactions on these trials will be penalized by a point system. Due to the concentration required in this task there will only be 20 reaction trials presented. Maximum effort will be required to maintain optimal performance in this task. Reaction time feedback will be provided during these trials. If you have any questions please ask them now.

Temporal Order Judgment Task

In the next section of the study you will not be required to give a fast reaction to one of the signals. Instead, you are asked to passively observe the preliminary warning signals and then the onset of one of the visual and one of the auditory signals at different inter-stimulus intervals. After the two signals have been extinguished by the experimenter you are then required to indicate which of the two stimuli you perceived as occurring first. You will make your decision known by depressing the appropriate button before you, labeled "Eye" or "Ear." Because there is no primary or auxiliary signal in this condition of the study there will not be a cue stimulus given during the preliminary warning signals. In other words the progression of events will be as follows: both signals will occur for a half second, then there will be a blank period for one and a half seconds, followed by a brief onset of both signals together. Then there will be a variable

delay after which the two signals will occur again at various interstimulus intervals. After they have been extinguished you are to indicate which stimulus occurred first. Two blocks of twenty trials will be administered with no feedback provided as to the accuracy of your judgments. Do you have any questions?

(After the original 40 TOJNO trials were obtained, four, interleaved staircases were begun and 60 final TOJNO trials were administered. Instructions in this final session were identical to the above. They were given verbally by the experimenter.)

Concurrent Temporal Order Judgment - Stimulus Identification - Reaction Time Task

Congratulations, you have survived this experiment to the final section. In the last task you will be required to react selectively to the primary signal while ignoring the auxiliary stimulus. This is identical to the complex reaction time task that you have already completed. The difference in this task is that as soon as you have responded, the experimenter will verbally query you concerning one of the modalities. For example, you may have just reacted to a primary visual signal and the experimenter may say "Tone." You should then verbally respond whether it was a high or low frequency tone and whether it occurred first or second relative to the visual signal. (Your response might be something like this: "Low, first.") As another example you may have just responded to the primary auditory signal and the experimenter may have stated "Light." In this case you may respond by saying "First, red" or "Amber, second."

Obviously another dimension has been added to the reaction time task and it will require sustained concentration if stable reaction time performance is to be realized. Throughout these trials reaction time feedback will be provided to inform you of your performance. No information will be given concerning the order judgment or identification task as these are merely subsidiary to the primary reaction time task. You are, however, requested to make your judgments and identifications as accurate as possible and, if you are unsure as to the nature of the signal queried or to its order, to force a guess. Remember that a random half of all trials will be catch trials in which the auxiliary signal will occur alone. Don't get caught on these trials. The best way to ensure a good performance is to concentrate on the appropriate signal and only worry about one trial at a time. If you have any questions please ask them now.

APPENDIX 3

THE "UP-AND-DOWN" STAIRCASE METHOD IN PSYCHOPHYSICS

The staircase method is best described by illustrating its use with a specific problem. The following example comes from Cornsweet (1962). The problem under consideration is to determine a subject's absolute threshold for the sound of a click. The experiment presents the first click at some arbitrary intensity and observes the subject's response. If the subject says 'yes' indicating the click was heard, the next stimulus is made less intense; if the subject says 'no' the following signal is made more intense. This process is continued until a criterion of performance or a 'number of trials' is reached.

According to Cornsweet (1962) four important conditions are predetermined by the experimenter: 1) what value of the stimulus to start the series, 2) how large the stimulus increments are to be, 3) what criterion is necessary to stop the series, and 4) when should the series be modified in any way.

The major advantage of the staircase method is its efficiency. "Once the first few stimuli are out of the way, all of the other stimuli are very near the threshold-level, each one contributing importantly to the final computed threshold-value" (Cornsweet (1962), p. 488). The major disadvantage of the method is that only after a few presentations, subjects become very much aware of the way in which the stimuli are being ordered. One way to reduce any artifacts due to subjective

awareness of the staircase procedure is to concurrently run two separate staircases alternating signal intensities from each on successive trials. Cornsweet (1962) even suggests going one step further. Instead of alternating from staircase "A" on the odd trials and staircase "B" on the even trials, randomly assign which staircase will be employed from trial to trial. As Cornsweet states: "When the random, double staircase method is used, S feels none of the constraint that goes with the single staircase method. . . . If, in fact, the two series do come together and then run along more or less horizontally, S must be responding to some aspect of the stimulus itself. . . This means that the possibility of the effects of series-interdependencies biasing the computed threshold-value is greatly reduced (p. 491)."

In the present experimentation, two randomized, 40-msec-step staircases were initiated. Four, 20-msec-step staircases were begun after a predetermined criterion of convergence was met; in this case, the mean position of the start and end of the second block of 20 trials was required to be less than two steps apart. Figure 24 illustrates typical TOJ performance as a result of both the dual 40-msec-step staircase procedure and the final four 20-msec-interleaved staircase method. Note that in both sets of series the staircases are initiated at half-step intervals apart so as to increase the precision in estimating the TOJ-ISI relationship.

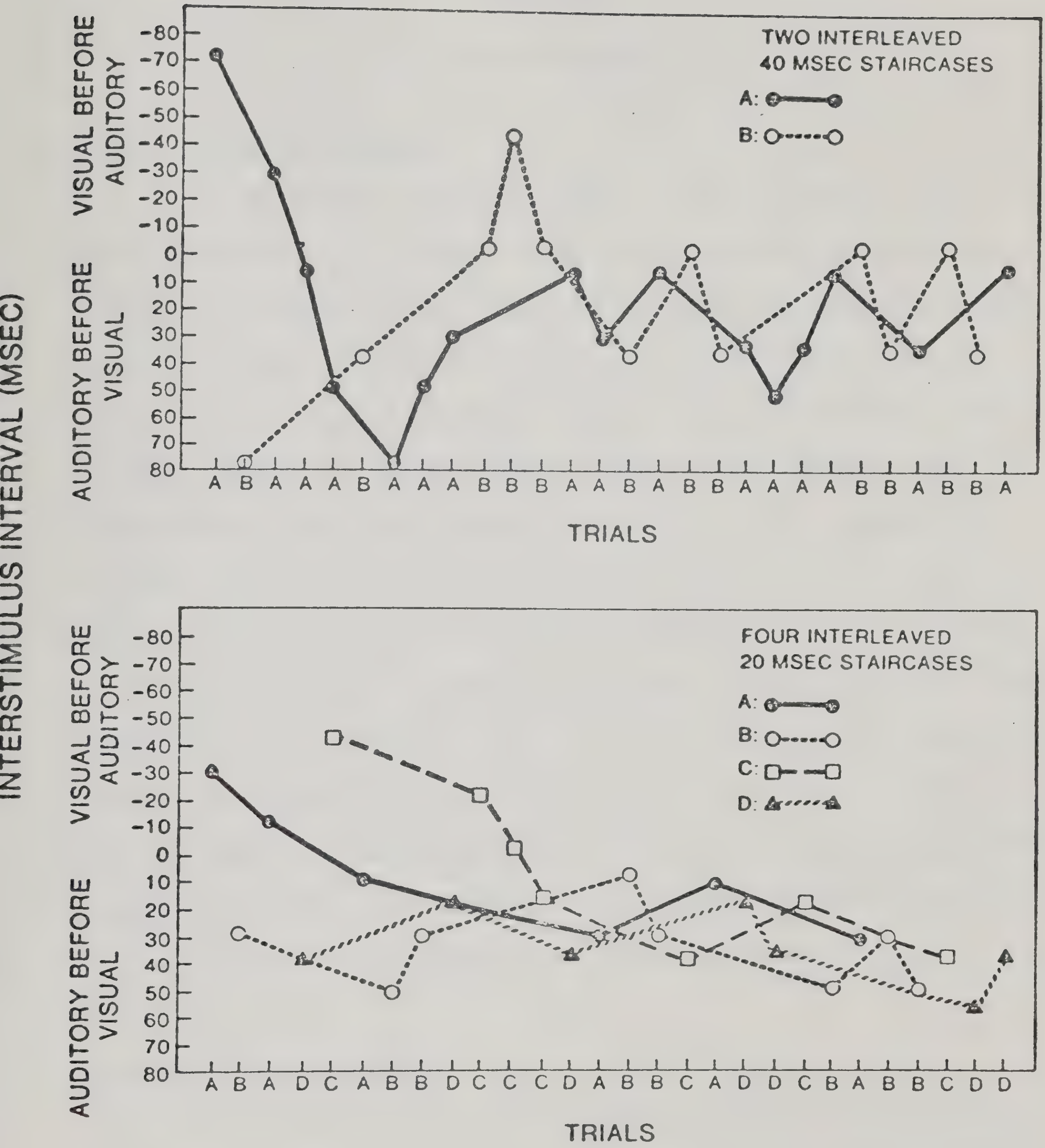


Figure 24. Typical TOJ performance with two- and four-interleaved randomized staircase series

APPENDIX 4

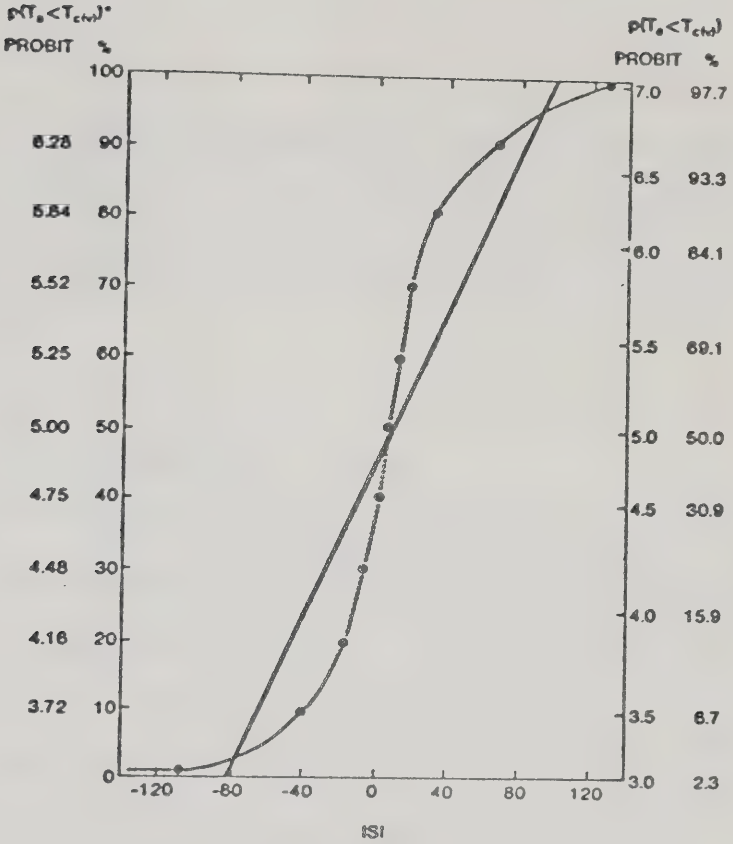
PROBIT ANALYSIS

History of Probit Analysis

It was Fechner who first referred to the fundamental idea of the probit method. In discussing the relationship of the difference between two weights with the proportion of trials in which the subject correctly judged which was the heavier, he suggested that when the weight differences were negligibly small a linear relationship would be found between the weight difference and a normal deviate. As Finney (1964) summarizes Fechner's logic: ". . . if the proportion of right answers were known for one weight difference, the factor of proportionality with the normal deviate could be estimated; estimates could then be made of the proportions corresponding to any other weight differences or vice versa (p. 43)." The fundamental idea of the probit method is a reduction of the sigmoid response curve to a straight line by means of a transformation of the responses. This straight line transformation allows for predictions to be made concerning the subjective response for any value along the stimulus continuum.

The Probit Transformation

The effect of transformation from percentages or proportions to probits is shown in Figure 25. The normal sigmoid curve of subjective response is shown here with the straight line obtained when data points are replotted on a linear probit scale. The abscissa from left to right is composed of negative to positive ISIs.



$^*p(T_a<T_{c(v)})$ = PROPORTION OF TRIALS THAT THE AUDITORY SIGNAL WAS PERCEIVED AS OCCURRING BEFORE THE CUTANEOUS (VISUAL) SIGNAL

Figure 25. Effect of the probit transformation

Along the left-hand vertical axis is a linear scale of percentages of "auditory signal perceived first" responses with their corresponding probit values, and on the right-hand axis is a linear scale of probits with their corresponding percentage values. As Finney (1964) describes the transformation effect, it "may be considered as a stretching of the left-hand scale to give that on the right-hand, during which process the sigmoid curve becomes straightened." The probit of the proportion P is defined as the abscissa which corresponds to a probability P in a normal distribution with mean 5 and variance 1. The probit of any expected proportion is related to ISI by the linear equation $y = 5 + 1/\sigma\ (x - \mu)$. By means of the probit transformation, the

results of an experiment may be used to give an estimate of this equation; particularly the median effective ISI may be estimated as that value of x that gives $y = 5$. This value of x is the experimentally derived PSS.

The Probit Regression Line

After experimental data on the relationship between ISI and temporal order judgments have been obtained, the TOJ proportions for each ISI must be converted to probits. A simplified version of the table prepared by Bliss (1935) and reproduced by Fisher and Yates (1948) is included as Table XIV. The obtained probits are then plotted against x, the values of ISI, and a straight line is drawn by eye to fit the points. The vertical deviations of the points are considered such that the distances from the provisional line for the various points are as short as possible; this is similar to the drawing of a line of best fit in a least-squares solution. The PSS is then estimated from the line as the point at which the regression line intersects the 50% point on the ordinate, the ISI at which $y = 5$. The slope of the line is an estimate of $1/\sigma$ and is obtained as the increase in y for a unit of increase in x. These two parameters are then substituted in the probit equation to give the estimated relationship between ISI and TOJ.

Test of Chi Square

To determine the adequacy of the equation derived and the actual relationship between ISI and TOJ, a test of x^2 (Fisher, 1944) is used. Basically a value of x^2 that is within the limits of random variation

Table XIV. Transformation of percentages to probits (from Finney, 1964)

%	0	1	2	3	4	5	6	7	8	9
0	-	2.67	2.95	3.12	3.25	3.36	3.45	3.52	3.59	3.66
10	3.72	3.77	3.82	3.87	3.92	3.96	4.01	4.05	4.08	4.12
20	4.16	4.19	4.23	4.26	4.29	4.33	4.36	4.39	4.42	4.45
30	4.48	4.50	4.53	4.56	4.59	4.61	4.64	4.67	4.69	4.72
40	4.75	4.77	4.80	4.82	4.85	4.87	4.90	4.92	4.95	4.97
50	5.00	5.03	5.05	5.08	5.10	5.13	5.15	5.18	5.20	5.23
60	5.25	5.28	5.31	5.33	5.36	5.39	5.41	5.44	5.47	5.50
70	5.52	5.55	5.58	5.61	5.64	5.67	5.71	5.74	5.77	5.81
80	5.84	5.88	5.92	5.95	5.99	6.04	6.08	6.13	6.18	6.23
90	6.28	6.34	6.41	6.48	6.55	6.64	6.75	6.88	7.05	7.33
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
99	7.33	7.37	7.41	7.46	7.51	7.58	7.65	7.75	7.88	8.09

indicates good agreement between ISI and probit points. All probit equations in the three experiments were satisfactory representations of the results of their respective experiments.

APPENDIX 5

RAW PROPORTIONS BY ISI

Ogives were fitted to the raw data to produce the psychometric functions reported in the Results section of Experiments I, II, and III. The raw data tabulated on the following pages are the actual proportions of the trials by ISI in which subjects reported that the auditory signal was perceived as occurring before either the cutaneous or visual stimulus.

EXPERIMENT I*

Subject 1

ISI

	-100	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	100
TOJNO	.00	.00	.00		.33	.0	.20	.0	.50	.77	.67	.71	1.00	1.00	1.00
TOJAUD		.00	.33	.50	.54	.50	.78	1.00	.83	1.00	1.00	.83		1.00	
TOJCUT				.00	.25	.20	.25	.20	.50	.88	.71	1.00	1.00		

Subject 2

ISI

	-100	-90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	100
TOJNO	.00		.67		.57		.00		.18		.50		.81		.86		1.00		1.00	1.00
TOJAUD		.00	.00	.40	.00	1.00	.43	.25	.43	1.00	.75	.33	.33	.62	.50	.80	.50	1.00	.75	1.00
TOJCUT			.00		1.00	.00	.33	.50	.33	.00	.75	.20	.25	.38	.33	.33	.33	1.00	1.00	

*In All Experiments: Proportions reflect "auditory first" responses; 10-15 trials in the middle of the distribution, 1-5 trials at the extremities. ISIs in milliseconds.

Due to the nature of the staircase procedure, some ISIs were not employed.

Subject 3

ISI

	-100	-90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	100
TOJNO	.00		.22		.38		.57		1.00		.86		.50		1.00		1.00		1.00	1.00
TOJAUD				.00	.00	.17	.33	.57	.33	.60	.67	1.00	.67	1.00	.50	.67	.33	1.00	.67	1.00
TOJCUT		.00	.00	.25	.83	.67	1.00	.60	.50	.40	.50	1.00	1.00	1.00	1.00	1.00	1.00			

Subject 4

ISI

	-100	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	80	100
TOJNO	.00	.00		.00	.00	.30	.71	.70	.33	.44	1.00	.55	1.00	1.00	1.00	1.00	1.00	1.00
TOJAUD			.67	.50	.75	.45	.43	.83	.86	1.00	1.00	.75	.75	1.00	1.00			
TOJCUT						.00	.00	.50	.14	.28	.44	1.00	1.00					

Subject 5

	ISI														
	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60
TOJNO	.00		.00		.33		.12		.80		.88		1.00		1.00
TOJAUD		.00	.00	.20	.43	.25	.83	.25	.60	.43	.80	1.00	1.00	1.00	
TOJCUT			.00	.-0	.00	.00	.25	.00	.00	.29	.50	.62	.50	.80	1.00

Subject 6

	ISI																		
	-100	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	100
TOJNO	.00	.50		.00		.00	.00	.14	.75	.58	1.00	1.00	1.00	.75		1.00		1.00	1.00
TOJAUD			.00	.00	.20	.14	.50	.50	.40	.57	.83	.80	.75	.75	.75		1.00		
TOJCUT				.00	.00	.00	.20	.25	.40	.00	.33	.38	1.00	.88	.75	1.00	1.00		

EXPERIMENT II

Subject 1

ISI

	-90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50
TOJNO	.00				.33	.29	.75	.33	1.00	1.00	.67	1.00	1.00	1.00	1.00
TOJAUD		.50	.50	.67	1.00	.67	.43	.50	.56	.60	1.00	.75	1.00	1.00	
TOJVIS				.00	.20	.33	.60	.86	.83	.60	1.00	1.00	1.00	1.00	

Subject 2

ISI

	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70
TOJNO				.00	.00	.17	.50	.38	1.00	.86	.25	.50	.67	.67	.50	
TOJAUD	.00	.00	.40	.50	.67	.20	.20	.67	.40	.60	.80	.50	1.00	.75		1.00
TOJVIS					.25	.60	.50	.33	.60	1.00	.50	1.00	.50	1.00	1.00	

Subject 3

	ISI															
	-100	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60
TOJNO	.00			.25	.00	.50	.60	.88	.71	1.00	.80	.75	1.00	1.00		1.00
TOJAUD	.50	1.00	.33	.50	.50	.50	.86	.00	.50	.00	1.00	.43	.67	1.00	1.00	
TOJVIS	.00	.25		.60	.00	.50	.56	.20	.57	.50	.75	1.00	.50	1.00	1.00	

Subject 4

	ISI																				
	-110	-100	-90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90
TOJNO						.00	.00	.14	.33	.60	.25	.43	.38	.50	.57	1.00	1.00				
TOJAUD	.00	.50	.62	.75	.71	.67	1.00	1.00	1.00												
TOJVIS												.00	.25	.40	.44	.25	.67	.50	.60	1.00	1.00

Subject 5

	ISI														
	-140	-130	-120	-110	-100	-90	-80	-70	-60	-50	-40	-30	-20	-10	0
TOJNO			.00	.00	.60	.60	.50	.50	.50	1.00	.83	.50	1.00	.80	1.00
TOJAUD	.00	.00	.25	.43	.50	.64	.86	.83	1.00	1.00					
TOJVIS						.00	.00	.20	.38	.42	.70	.75	.80	1.00	1.00

Subject 6

	ISI														
	-130	-110	-100	-90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20
TOJNO			.20	.25	.00	.75	.58	.36	1.00						
TOJAUD		.20	.33	.80	.00	.50	.33	.50	.29	.50	.71	.75	1.00		
TOJVIS	.00	.20		.67	.00	.50	.33	.83	.56	1.00	.50	1.00	.00	1.00	1.00

EXPERIMENT III

Subject 1

	ISI														
	-270	-250	-230	-220	-210	-200	-190	-180	-170	-160	-150	-140	-130	-120	-100
TOJNO												.00	.00	.20	.20
TOJAUD	.00	.50	.50	.00	.50	.17	.17	.67	.67	.57	.33	.80	1.00	1.00	
TOJVIS															

Subject 1 (continued)

	ISI														
	-90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50
TOJNO	.45	.40	.50	.56	1.00	.40	1.00	1.00							
TOJAUD															
TOJVIS				.00		.50	.00	.17	.43	.45	.56	.88	.62	1.00	1.00

Subject 2

	ISI												
	-160	-150	-140	-130	-120	-110	-100	-90	-80	-70	-60	-50	-40
TOJNO							.00	.33	.00	.50	.29	.50	.71
TOJAUD	.00	.00	.33	.30	.50	.69	.22	1.00	.78	1.00	1.00		1.00
TOJVIS													

Subject 2 (continued)

	ISI											
	-30	-20	-10	0	10	20	30	40	50	60	70	90
TOJNO	.50	.40	.57	.60	.75	.67	1.00					
TOJAUD												
TOJVIS				.00	.33	.33	.25	.50	.33	.67		

Subject 3

	ISI														
	-210	-190	-170	-160	-150	-140	-130	-120	-110	-100	-90	-80	-70	-60	-50
TOJNO		.00	.33	.00	1.00	.67	1.00	.67	.50	.50	.50	.50	.75	.67	1.00
TOJAUD	.00	.33	.60	.00	1.00	.58	1.00	.57	1.00	.75					
TOJVIS														.00	.00

Subject 3 (continued)

	ISI														
	-40	-30	-20	-10	0	10	20	30	40	50	60	70	90	110	130
TOJNO	1.00	.00	1.00	.67	1.00	1.00	1.00								
TOJAUD															
TOJVIS	.33	.50	.20	.00	.40	.50	.25	.43	.40	.80	.50	.67	.67	.50	1.00

Subject 4

	ISI									
	-170	-160	-150	-140	-130	-120	-110	-100	-90	-80
TOJNO						.40	.33	.33	.45	.30
TOJAUD			.50		.67	.00	.50	.33	.67	.67
TOJVIS	.-0		1.00		.67	.00	.50	.40	.62	.67

Subject 4 (continued)

	ISI									
	-70	-60	-50	-40	-30	-20	-10	0	10	20
TOJNO	.62	.71								
TOJAUD	1.00	.20								
TOJVIS	.80	.67	1.00	.83		1.00		.50		1.00

Subject 5

	ISI								
	-100	-90	-80	-70	-60	-50	-40	-30	-20
TOJNO	.00	.33		.67	.00	.67	.33	.00	.25
TOJAUD	.00	.50	.40	.17	.50	.40	.33	.62	.50
TOJVIS					.00	1.00	.50	.50	.33

Subject 5 (continued)

	ISI									
	-10	0	10	20	30	40	50	60	70	80
TOJNO	.75	.38	.33	.75	1.00	.80	.67	.50	1.00	1.00
TOJAUD	.50	.40	.50	1.00	1.00	1.00				
TOJVIS	.33	.44	.12	.70	.60	.80	1.00	1.00		

Subject 6

	ISI												
	-200	-180	-170	-160	-150	-140	-130	-120	-110	-100	-90	-80	-70
TOJNO			.00	.00	.50	.25	.62	.43	.71	.83	.67	.33	1.00
TOJAUD	.00	.50	.00	.33	.33	.38	.64	.75	.75	1.00	1.00	.67	
TOJVIS										.00	.00	.50	.75

Subject 6 (continued)

	ISI												
	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60
TOJNO	.25		1.00										
TOJAUD	1.00												
TOJVIS	.67	.00	.00	.33	.00	.00	.14	.57	.86	.75	.50	1.00	1.00

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